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IGNEOUS ROCK-SERIES AND MIXED IGNEOUS ROCKS

I. IGNEOUS ROCK-SERIES

By an igneous *rock-series* we may understand an assemblage of rock-types, differing perhaps widely but still with a certain community of characters, associated in the same district and belonging to the same suite of eruptions, and further, holding a similar position in the scheme of igneous rocks belonging to that suite. Adopting the differentiation hypothesis, we may conceive them as derivatives of the same order from one common source, resulting from differentiation along similar lines and to the same degree. The fundamental characteristics of such a series, having regard to chemical composition, are of two kinds: (1) those belonging to the individual rock-types and shared by all the types included in the series (*e. g.*, each member is rich in some particular constituent, as compared with average igneous rocks of like silica-percentage); and (2) those belonging to the assemblage of types as a whole, depending upon variations in the composition of the members as compared with one another (*e. g.*, a particular constituent may in one rock-series fall off steadily with increasing silica-percentage, in another series it may rise to a maximum and then decline). These characteristics, and especially those which fall under the second head,

come out most clearly when exhibited graphically in a diagram such as was first used by Professor Iddings.[1]

The diagram is easily constructed from the analyses of the rocks (Fig. 1). Two rectangular axes, *OX* and *OY*, are drawn, horizontally and vertically, each of length equal to 100 parts of some convenient scale. We cut off the abscissa *OM* to represent the silica-percentage of any one of the rocks, and erect ordinates *MP*, *MQ*, etc., to represent the corresponding percentages of the other oxides, which we may conveniently speak of as the bases. This is done for each of the rocks. Then joining *P P'*. . . . ., etc., we have a line which represents the variation of one particular base in this rock-series, and similarly for the other bases. Iddings converts the figures of the analyses into molecular proportions before expressing them graphically; but for our present purposes nothing would be gained by doing this, and we may follow the simpler method.

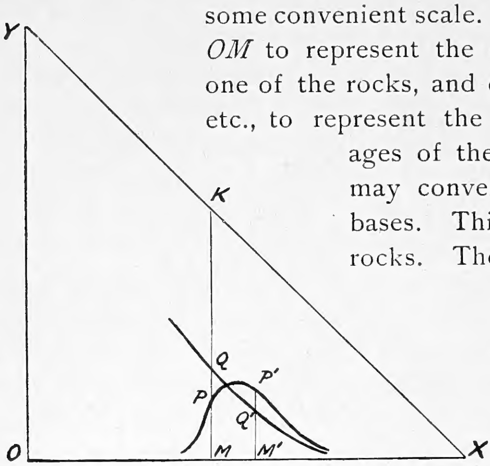


FIG. 1.

The lines *PP'*. . . . ., etc., *QQ'*. . . . ., etc., as thus laid down, are broken or zigzag lines. We find, however, that in a rock-series in the strict sense of Brögger the departures from regularity are not great. Minor irregularities may arise from the variation found among different specimens of the same rock-type, or from errors in the analyses. To obtain a clearer picture of the essential variations characteristic of the series it will be legitimate to *smooth* the lines, *i. e.*, to convert them into flowing curves passing as nearly as may be through the proper points. The diagram then affords a graphic representation of the chemical characteristics of the given rock-series. We may use it, for

[1] Origin of Igneous Rocks, Bull. Phil. Soc. Wash. (1892), Vol. XII, pp. 89–214.

example, to obtain by interpolation the chemical composition of a member of the series intermediate between two known members. To predict by extrapolation the composition of a hypothetical member beyond the limits covered by actual representatives is, of course, a more speculative matter, since we have no precise data for prolonging the empirical curves. There are, however, some obvious considerations. The sum of all the ordinates *MP*, *MQ*, etc., for a given rock must be equal to *MK*, *K* being the point in which the vertical through *M* meets the straight line *YX*. Hence all the curves must be contained within the triangle *YOX* : prolonged to the right, they must all meet at the point *X*, corresponding with a hypothetical rock with 100 per cent. of silica : prolonged to the left, they must meet the line *OY* in points such that the sum of all the ordinates is equal to *OY*, corresponding with a hypothetical rock devoid of silica.

The simplest kind of variation conceivable is found when, with increasing silica-percentage, the percentage of each base changes at a constant rate (different for each). In other words, the percentage of each base is then a linear function of the silica-percentage. Such a series may be termed a *linear series*, and its geometrical characteristic is that all the curves in the diagram become straight lines. In the wholly ideal case of a linear series extending to the ends of the scale, all these straight lines would decline towards the right and meet at the point *X*. It is safe to say that no such series exists in nature, nor has any natural series been described corresponding with a portion of such a diagram. It may, however be inquired whether, or to what extent, natural rock-series fulfill the condition of linearity within the limits of the actual representatives of the series. Professor Brögger, in his memoir on the grorudite-tinguaite-series,[1] makes approximate linearity a characteristic property of a *Gesteinsserie* : this is implied in his dictum "every mean of a number of members of the series corresponds approximately with a possible member of the series." But it is easy to show by plotting graphically the analyses which he gives that this

[1] Eruptivgesteine des Kristianiagebietes (1894), Part I, p. 175.

must not be understood in too literal a sense. Indeed, Brögger himself abandons the principle; for, in calculating by extrapolation the composition of a hypothetical end-member of the series, he supposes that, while some of the bases vary in arithmetical, others vary in geometrical proportion: a supposition inconsistent with linearity.[1] If a few rock-series be actually plotted in diagrams, it soon becomes apparent that, while some of the bases often give sensibly straight lines within the limits of the actual rocks, others give lines very decidedly curved. We may note in passing that some kinds of variation in igneous rock-masses connected with differentiation *in situ* involve much more considerable departures from the linear type. Such, for instance, is the "concentration" of the more basic constituents in certain parts of a rock-body, as investigated by Vogt and others.

It appears then that in general the diagram of a rock-series will consist of *curved* lines to indicate the variations in percentage amount of the several bases. Of these curves we may disdistinguish two kinds: (*a*) When the constituent in question first increases to a maximum and then decreases, or increases first more rapidly and then less rapidly, or decreases first less rapidly and then more rapidly, the curve will be *convex* upward; (*b*) When it decreases to a minimum and then increases, or decreases first more rapidly and then less rapidly, or increases first less rapidly and then more rapidly, the curve will be *concave* upward. This classification is not an exhaustive one, for there may be curves which are inflected, being convex in one part and concave in another, but it will be sufficient to consider the simpler cases. Since the sum of the ordinates for all the bases falls off steadily in linear fashion, its curve of variation being the straight line YX, it follows that in any series, other than an ideal linear one, some of the bases must give convex and others concave curves.

II. MIXED IGNEOUS ROCKS

Considerable differences in composition may exist among members of the same rock-series, and still greater differences are

[1] *Ibid.*, p. 172.

found among members of different series belonging to the same suite of eruptions in one district. Most of those who have discussed the origin of igneous rocks have sought the cause of this diversity in various processes of diffusion, etc., commonly spoken of as *differentiation* in rock-magmas; it is no part of our present object to discuss these processes. Some geologists, however, including Professor Sollas and Dr. Johnston-Lavis, have laid stress on the possible origin of certain igneous rocks by *admixture*, a process in some sense the reverse of differentiation, and this question we shall consider more closely.

We may distinguish *a priori* three cases:

1. Mixture of two fluid rock-magmas.
2. Permeation or impregnation of a solid rock by a fluid magma with consequent reactions between the two.
3. Inclusion of solid rock-fragments (xenoliths of Sollas) in a fluid magma and their partial or total dissolution and incorporation in the magma.

In the first case the two rocks involved must be of the same age and presumably from a common origin. In the second and third cases this is not necessarily true, and the solid rock need not even be an igneous one; but, when we examine actual instances which have been described, it seems probable that here also admixture does not in fact take place on an important scale except between igneous rocks of cognate origin. Lacroix, in his exhaustive memoir on xenoliths,[1] distinguishes two categories, *enclaves énallogènes*, which are not related in composition or by origin to the enclosing rock (*e. g.*, limestone fragments in trachyte), and *enclaves homœogènes*, which do present more or less resemblance in composition and origin to the rock in which they are enclosed (*e. g.*, olivine-nodules in basalt). Similarity of mineralogical composition is, however, by no means a sufficient test of community of origin among igneous rocks, and instances may easily be cited (*e. g.*, some cases of gabbro enclosed in granite) which would be placed by Lacroix under the former of his two heads, but in which there exists, despite differences of

[1] Les enclaves des roches volcaniques, Macon, 1893.

composition, an essential and close relationship between the two rocks thus associated. Instead of using the above terms in an altered sense, it will be better to coin new ones, and we shall accordingly recognize two kinds of xenoliths, *accidental* and *cognate*. This distinction is based, not on difference or likeness in composition, but on the existence, in the latter kind, of a genetic relationship between the enclosed and the enclosing rock, which is wanting in the former kind. A like distinction will apply to the permeation of a solid rock-body by a fluid magma. Now although both permeation and the incorporation of xenoliths are known in instances which fall under the accidental category, they are known thus only as quite local phenomena. If new rocks of any considerable extent or importance are actually produced by admixture, it is by admixture of two cognate rocks. One reason for this is doubtless to be found in the consideration that reactions between a solid rock and a fluid magma will be promoted by the former being still at a high temperature when the latter comes into contact with it. There may be other reasons of a chemical nature.

Without discussing at once whether admixture is a factor of prime importance in the genesis of igneous rocks, we may inquire what kind of rocks are to be expected from such a mode of origin. We take first the simplest case, that of admixture between two members of the same rock-series. The chemical composition of the resulting product will be the same whether both or only one of the two rocks be fluid at the time when they are brought together. If the series be a linear one, the admixture will produce a rock having the composition of a possible member of the series. This is Brögger's principle already quoted, which, however, requires to be limited by the condition here imposed. In the more general case the mixed rock will not correspond with a possible member of the series, but will differ more or less in composition from that possible member which has a like silica-percentage. This is clear when expressed graphically (Fig. 2). If *OM* and *OM'* represent the silica-percentages of the two component rocks, and their proportions

in the mixture be a to b, then Om will represent the silica-percentage of the mixture, m being the point which divides MM' in the ratio b to a. (The empty portion of the diagram is omitted to save space.) If PpP' be the curve of variation of some one of the bases, then mp' in the figure represents the percentage of that base in the mixed rock. The percentage in the corresponding member of the rock-series is represented by mp, and the mixed rock is therefore deficient in this base as compared with the latter, the defect being represented by pp'. Similarly a different base, having QqQ' for its curve, will be in excess in the mixed rock as compared with the corresponding member of the rock series, the excess being represented by qq'. It is evident that there will be a defect or an excess according as the curve is convex or concave between the points corresponding with the two component rocks. The defect or excess will be greater, *ceteris paribus*, the farther apart the two component rocks are in the series. It is easy to see that, given a series such that its diagram has markedly curved lines, the result of the admixture of two members may be something not only foreign to the series, but highly peculiar by comparison with igneous rocks in general.

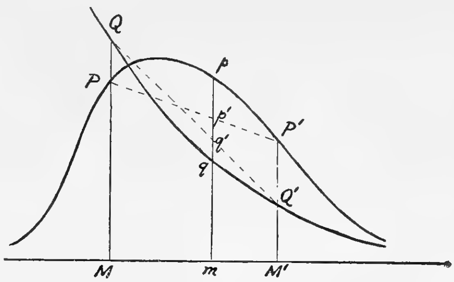


FIG. 2.

This may be still more strikingly the case in the admixture of two rocks which have no such close relation with one another. In illustration we take two simple cases of accidental xenoliths. First suppose a rock-magma to become enriched in silica by dissolving quartz, of extraneous origin, a parts of the magma taking up b parts of quartz. Dividing MX at m in the ratio b to a, we have Om to represent the silica-percentage of the resulting mixed rock (Fig 3). If MP, MQ, etc., represent the percentages of the various bases in the original magma, then mp', mq', etc., will represent them in the mixed rock, these ordinates being

cut off by straight lines joining the points P, Q, etc., to X. If we now draw curves such as Pp, Qq, etc., to indicate in a general way the usual behavior of the several bases in average igneous rocks, we obtain some idea of the respects in which the mixed rock is peculiar. In the diagram it is shown as being unusually poor in the first base and rich in the second.

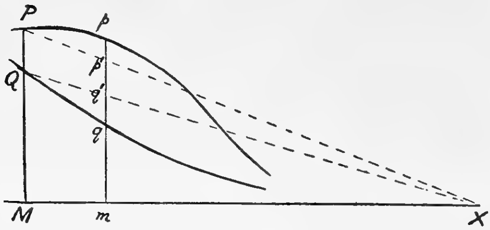


FIG. 3.

Next suppose a rock-magma to become enriched in lime by dissolving limestone, in the proportion of a parts of the magma to b parts of lime. The result is illustrated by the diagram, Fig. 4. The line OM is divided at m in the ratio a to b. If MP represents the lime in the original magma, mp' will represent that in the mixture, this ordinate being cut off by the straight line joining P to Y. If MQ and MR represent two other bases in the original magma, mq' and mr' will represent them in the mixture, these ordinates being cut off by straight lines joining the points Q and R to O. It is noteworthy that the mixture, as compared with ordinary igneous rocks, may be unduly rich in other bases besides lime: in the figure this is the case with the second of the two bases represented (curve passing through R).

The foregoing general considerations lead us to anticipate that a rock resulting from admixture may be, and in many cases must be, of peculiar chemical composition. A rock-series, for example, may consist of basalt, pyroxene-andesite, dacite, and rhyolite; but it does not follow that a mixture of basalt and rhyolite will produce an andesite or a dacite. Still less will a basalt be converted into an andesite by addition of silica, or a rhyolite into a dacite by addition of lime. The processes by which different igneous rocks have been evolved from a common stock are too complex and subtle to be reversible, at least by so crude a method as that of admixture. To illustrate these remarks from

actual instances, we have only to take a collection of trustworthy rock-analyses, such as that published by Clarke and Hillebrand,[1] and plot diagrams upon a convenient scale. The lavas of the Lassen Peak region in California afford a good example. Here the curves of some of the bases approximate to straight lines throughout a considerable part of their extent. Towards the basic end, however, the alumina-line becomes strongly convex and those for magnesia and lime decidedly concave, while the soda-line is slightly but distinctly convex throughout. This diagram includes the normal basalts, andesites, dacites, and rhyolites; and the very slight amount of smoothing required to obtain flowing curves stamps this group of rocks as a natural series. The quartz-basalts, on the other hand, refuse to adapt themselves to this scheme, and their abnormal composition is clearly brought out by plotting their analyses on the same diagram. In their content of lime and potash they do not differ notably from normal rocks of like silica-percentage, but they show a marked deficiency in alumina and ferric oxide, and to a less degree in soda, and an excess of magnesia and ferrous oxide.

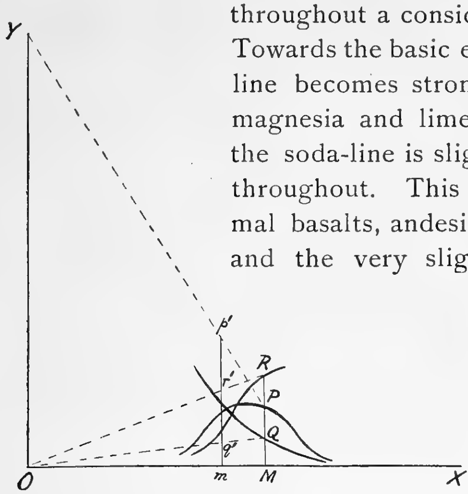


FIG. 4.

Although natural series of igneous rocks differ considerably from one another, they nevertheless possess certain broad characteristics in common. This is recognized by the very general practice of speaking roughly of acid, intermediate, and basic rocks, etc., as having more or less distinctive characters; which tacitly assumes that, in the broadest view, they fall approximately into a single line. Given a large number of analyses of normal (unmixed) igneous rocks, we might average the composition of those having like silica-percentages, and construct

[1] Analyses of Rocks, Bull. No. 148, U. S. Geol. Surv. 1897.

from such averages a diagram expressing the variation of the several bases. Further, we might note the limits of variation of each base within each group averaged, and express these limits also on the diagram. Each base would therefore be represented, not by a simple curve, but by a curved band of varying width. A still further refinement would be to indicate, say by different depths of color within the bands, the frequency of different degrees of departure from the average. On such a diagram it would be possible to test with some precision the principle here advanced, that mixtures, even of two normal igneous rocks and still more of an igneous and a sedimentary rock, must often be abnormal in chemical composition.

So much labor is, however, not necessary for our present purpose. We have hitherto considered only the bulk analyses of the rocks; but we know that a close relation exists between the chemical composition and the mineralogical; a relation which is a matter of very nice adjustment. Expressing it in a crude empirical way, we may say that the chemical variation evinced in normal igneous rocks is not of an arbitrary kind, but is such that the rock-magmas have been able to crystallize as mineral-aggregates consisting of species selected from a comparatively small category, and selected subject to certain laws of paragenesis which control the permissible associations of those mineral species. In a natural assemblage of rock types, whether a "Gesteinsserie," a "Faciessuite," or any other kind of grouping, the limitations are of course narrower still. To inquire into the significance or rationale of such rules would be to enter upon a theoretical discussion of the processes of differentiation, a subject outside our scope: they are introduced here as affording in great measure a test for mixed igneous rocks. For it follows that any variation of an *arbitrary* kind (*i. e.*, not on the lines of magmatic differentiation) imposed on the *chemical* composition of an igneous rock-magma may produce much more considerable modification in the *mineral* composition of the resulting rock. It is well known that, when a magma has absorbed material from sedimentary rocks, this often results in the formation of such

minerals as cordierite, sillimanite, corundum, spinel, idocrase, and others, which are either quite foreign to normal igneous rocks or at least foreign to rocks of the general type of those concerned. A mixture of two igneous rocks will in general show less obvious peculiarity, but it may still be expected to betray itself in the occurrence of unusual minerals, unusual mineral-associations, or unusual relative proportions of the constituent minerals. That it often does so betray itself in a fashion quite unmistakable, is proved by numerous examples of undoubted mixed rocks which have come under the notice of the present writer.

The question here broached has a very direct application to a subject now much in the minds of petrologists, viz., the endeavor to arrive at some natural (as opposed to a merely Linnæan) classification of igneous rocks. Such a classification must be based, confessedly or implicitly, upon fundamental genetic considerations, and primarily upon the mode of operation of the processes of differentiation in rock-magmas. Rocks resulting from admixture must therefore be excluded from the main scheme and relegated to an appendix. Any discussion which tends to the recognition of this principle and to the establishment of some criterion of distinction will forward the object by disembarrassing the problem of a disturbing element.

ALFRED HARKER.

ON THE HABITAT OF THE EARLY VERTEBRATES

If we take the record as it stands, the appearance of the fishes, the first known vertebrates, is one of the most abrupt and dramatic in the life-history of the earth. They seem to come trooping on the stage of action from some concealed source in full company and clothed in varied and curious armor, and at once a battle scene of prodigious range and duration begins. There had been some feeble premonitions, but these had revealed little of the coming drama. That there had been a long series of preliminary trainings, with trials and changes of armor, and rehearsals, and shiftings of parts, we cannot doubt, but where and how this transpired has been an unsolved mystery, though we have tried industriously to get behind the scenes.

The trivial premonitory signs of the apparition, even when interpreted by retrospective light, only serve to render their meagerness the more singular. If the fishes were armored in the Ordovician period, as the Colorado relics found by Walcott seem to show, and if these mail-clad fishes continued to live in the seas and to develop into the panoplied host that made its apparition during the transition stage from the Silurian to the Devonian, why did they not leave a more fitting registration of their presence? The "imperfection of the geological record" is indeed great, but in seas that preserved soft medusæ and delicate graptolites, it would seem that armored fish should have left abundant and substantial signs of themselves, if they were there. The Trenton relics of Colorado, if taken at their fullest assigned value, help to make such a record, it is true, but at the same time they emphasize its scantiness and nullify the familiar appeal to an unfossilizable softness of structure and perishableness of parts. While they contribute a little to the record, the chief effect of their discovery is to greatly strengthen the opinion long entertained that the fishes must have had a very protracted

pre-Devonian history, and to reënforce the conviction that the evolution of full suites of armor and varied forms of dentition was the work of a prolonged period and had almost necessarily many fossilizable stages previous to the striking display in the Devonian period and this conviction becomes the more firm when it is considered that the differentiation and the armoring extended not only to many different orders, but to subclasses and even classes. If Walcott's interpretations be accepted to relieve the dearth of the record, they must also be accepted as showing susceptibility to fossilization so much the earlier.

As the record now stands, there are fragments of plates, scales, and a supposed notochord from the Trenton of Colorado; but a dearth everywhere else in the widespread and well-studied Ordovician and throughout the early and middle Silurian. Then, in the transitional stages from the Silurian to the Devonian, fish remains appear on both continents, and before the Devonian has passed, they present a rich and varied deployment, embracing not only the two classes *Agnatha* (jawless fishes, *Cyclostomata*) and *Pisces* (true fishes) but all the known subclasses of these and a majority of their orders, according to the most recent authoritative classification.

The physical and biological associations of this extraordinary deployment were peculiar. On neither continent do fish remains appear abundantly in the open sea deposits. They are confined chiefly to the sediments of inland waters or of littoral zones or of embayed arms of the sea. The fish of the Corniferous limestone, perhaps most nearly an exception to this generalization, may properly be put in the last class, for the Corniferous beds were laid down in a great bay with only limited connection with the sea, though the fauna was truly marine.

In the Ludlow "bone bed" of England, where they first make their appearance in abundance, the fish remains are associated with Eurypterids, probably the most gigantic Crustaceans that have ever lived, some of them attaining two meters in length. There is the same association on the continent, notably in the island of Oesel in the Russian Baltic and in Podolia and Galicia,

and so again in the Waterlime group of America in which the *Pteraspis Americana* of Claypole occurs. The physical conditions in all these cases seem to have been peculiar, and in the case of the Waterlime group they were singularly so, for they permitted a host of these large Eurypterids and other Crustaceans to flourish in seeming luxuriance, while only a meager and pauperate marine fauna found an occasional entrance into the series. The conditions seem to have been congenial to the fish and Eurypterids but not to a typical marine fauna.

In the Old Red Sandstone phase of the Devonian both in Europe and America a similar association obtained. A most extraordinary group of fishes and a family of most gigantic Crustaceans flourished where marine life found only an occasional and meager presence. These few marine forms, here and there in a massive deposit, no more imply prevalent salt water than the present marine species in the Bay of San Francisco imply that the gravels, sands and silts of the valley of California and of the Great Basin, which seem to be analogues of the Old Red Sandstone, are prevailingly marine. The further association of the fishes and Eurypterids with land plants and fresh water mollusks, together with a total absence of marine relics from the same beds, leaves no solid ground for hesitating to accept the dominant view of English and other geologists that the typical Old Red Sandstone and its homologues are the deposits of fresh waters and that both the fishes and the Eurypterids found congenial conditions of life in them. As fishes and Eurypterids were found both earlier and later in marine deposits the question arises: *Were the fishes and Eurypterids primarily marine and later became adapted to fresh water, or were they primarily fresh-water forms which were occasionally carried out to sea, and which later became adapted to salt water?* The two cases do not necessarily require an identical answer, but the singular association of the two in unusual display under peculiar conditions and on both continents strongly implies a community of habit, at least at the stages in question. The association is one of the most unique faunal and physical combinations of geologic history.

The earlier occurrence of the Eurypterids in marine deposits is almost as limited as that of the fishes, and yet they were well adapted to fossilization and were actually fossilized as far back as pre-Cambrian times, as Walcott has recently shown by their discovery in the Belt Mountain terrane of Montana. Of about a dozen known genera of Eurypterids, only two or three of those least well known are without associations with formations regarded as fresh water. The relics found in marine sediments may be attributed to transportation from the land just as is done in the case of the terrestrial plants and land insects not infrequently found in marine beds; but transportation in the opposite direction cannot be assigned. In the Ordovician but a single Eurypterid representative is known to occur and of this very little is known. In the pre-Cambrian beds of Montana a more abundant presence seems to be indicated, but little has yet been learned of the concurrent physical conditions. The thousands of Crustacean fragments are associated with a few trails assigned to annelids and some that are possibly molluscan or crustacean, and the inference is that the deposits were made in the sea. From the occurrence of Eurypterids first in marine beds apparently and later in fresh-water deposits it has been inferred that they were originally sea-dwellers and later became adapted to landwaters, but the meagerness of their marine record on the one hand, and their abundance and fine preservation in the fresh-water deposits on the other, give point to the question whether their early marine record is anything more than the chance deposit of river forms borne out to sea. When it is considered that the records of acknowledged marine types are, on the whole, good as such things go, and have been widely and well-studied, there is an incongruity in the case of both the fishes and the Eurypterids between the meager marine records of the Ordovician and Silurian, and the impressive fresh-water record of the same forms in the Old Red Sandstone phase of the Devonian, and this incongruity may well be regarded as significant.

There is reason to believe that opinion has been much influenced — more or less unconsciously no doubt — by general

presumptions, rather than specific ones. There is a strong general presumption, based on theory and observation, that the earliest life was marine and hence that in the gross the course of migration has been from the sea to the land and to the air. But this should weigh nothing in particular cases not in conflict with it, for the descent of reptiles and mammals from the land to the sea is well established, and this in no way contravenes their remote ascension from a marine ancestry. It may be equally true that the fish and the Eurypterids descended from the rivers to the sea in the mid-Paleozoic, though their remote ancestors may have ascended from it.

In dealing with the specific presumptions of the case it is to be noted that the relics of river faunas are imminently liable to be borne down to the sea, while transportation in the opposite direction is unassignable. The presumption is that a land or fresh-water fauna will be somewhat represented in contemporaneous marine sediments if it be readily fossilizable. The fragments of fish and Eurypterids in the marine beds previous to the transition stage at the close of the Silurian are not more than could be expected if fish and Eurypterids were living in the streams of those times, but entirely absent from the seas. Indeed the record is rather scant even on this assumption.

A more or less widely accepted presumption regarding the early states of the land has possibly also weighted against the hypothesis that the fishes had their early development in the land waters, viz., the presumption that the land was without vegetal clothing, and that hence its waters were sterile and unsuited to life. Against this presumption there are several important considerations. If the land were naked, not only would the streams be sterile and silty from the unrestrained wash of the surface, but the waters of the sea border would also be similarly affected in some notable degree. Sea life should have avoided rather than sought the sterile, silty, shore waters. But the abundance of littoral life in the early Paleozoic fails to support this view.

Moreover, if the land were unprotected by vegetation, the rate of transportation of loosened surface materials would probably have been too great to permit complete chemical disintegration. As fast as crystalline grains were separated from their fellow grains by disintegration acting at their contacts, or along cleavage planes, they would doubtless have been promptly carried away to sea and the sands and silts would have been arkose in type. But as far down as the Cambrian at least they are distinctly not so, as a general rule. They are as pronouncedly disintegration-products as in any later age. The Upper Cambrian sandstone of the American interior is a most typical example of a thoroughly disintegrated product. The Huronian series, as developed about the Upper Great Lakes, bears scarcely less distinctive evidence of the dominance of disintegrating agencies than the Mesozoic and Cenozoic terranes on whose origins the influence of an ample clothing of vegetation wrought its full effects.

Still further, the voluminous carbonaceous deposits of the Huronian give support to the assumption that at least lowland vegetation then prevailed in abundance. These carbonaceous deposits have been compared in respect to the amount of carbon with the coal beds of the Carboniferous and Cretaceous periods, and not without some show of justice.

There are good reasons therefore for displacing the presumption, rather current in the earlier half of the century, that the lands of the older Paleozoic periods were barren of vegetation and for the substitution of the presumption that land vegetation was prevalent as far back as the shore deposits display the residuum of complete disintegration and abound in the relics of sea life. Beyond that, where the schists do not radically differ in chemical constitution from the igneous rocks, the era of a naked earth and the reign of disaggregation with slight decomposition may be placed amid the other mysteries of the Basement Complex.

The richness of littoral marine life, at least as early as the Cambrian, the carbonaceous deposits of the Huronian and the

chemical nature of all the Paleozoic and most of the Proterozoic strata, afford, in my judgment, ample ground for the presumption that vegetation clothed the land from a date long anterior to the Paleozoic era and that the land waters were capable of supporting their own appropriate fauna, as well as contributing to the support of that of the sea border.

Now there is one distinctive characteristic of land waters that deserves consideration in the study of the evolution of the early vertebrates, because it was a strenuous dynamic condition constantly impressed upon their fauna. It is their most familiar and essential feature, *their flow*. Neglecting lakes, which are mere incidents, land waters are distinguished by persistent and usually rather rapid motion in a fixed direction, and this is an insistent physical condition to which their fauna must adapt itself. Fortunately this adaptation must take a tangible form, whereas adaptation to the freshness of the water is accomplished by obscure modifications which are not as yet detectable. In flowing water, the animal must maintain its position against the current either by a contact of some resisting kind with the bottom of the stream, or must be provided with an effective mode of propulsion competent to meet the constant force of the current without undue draft on the vital resources; otherwise the animal would be swept out to sea and its race be ended as a stream-dweller. It is different with ocean currents, for they return upon themselves and an animal may yield to them without losing its marine habitat; and besides, they are usually much feebler than river currents.

A glance at the faunas of existing streams, which represent the outcome of ages of trial, shows only three prominent groups of animals that have accomplished the adaptation. The minor instances are negligible. The successful cases are, first and foremost, fish, second, certain mollusks that crawl on the bottom with firm contact, and third, certain crustaceans that are provided with numerous sharp claws that give them ready catch and hold upon the stream bed. The brachiopods that are free in youth, but sessile or pediceled in later life, the cephalopods that are

floating or swimming forms, the corals, the chrinoids, the echinoids, and many other sea forms of ancient history and long opportunity, have not made an effective entrance into the streams during geologic time; and this is probably not wholly, and perhaps not chiefly, due to the sweetness of the waters.

A compact form of body presents obvious advantages, except as environment or food or locomotion requires some departure from it, and the vast majority of animals are more or less rotund, and their locomotive devices are adjusted to this form. But the rotund form offers much resistance to rapid currents and unfits the animal for effective stream life unless it persistently hugs the bottom. Neither the rotund floaters and swimmers like the ancient cephalopods, nor the cilliated spawn of the sessile forms are well adapted to resist the unceasing pressure of a rapid stream, and these are practically absent from river faunas.

There is only one conspicuous type that is facilely suited to free life, independent of the bottom, in swift streams, and that is the fish-form. The form and the motion of the typical fish are a close imitation of the form and motion of wisps of water-grass passively shaped and gracefully waved by the pulsations of the current. The rhythmical undulations of the lamprey which perhaps best illustrates the primitive vertebrate form, and is itself archaic in structure, are an almost perfect embodiment in the active voice of the passive undulations of ropes of river confervæ. The movement of the fish is produced by alternate rhythmical contractions of the side muscles, by which the pressure of the fish's body is brought to bear in successive waves against the water of the incurved sections. In the movement of a rope of vegetation in a pulsating current, it is the pressure of the pulses of water against the sides of the rope that give the incurvations. The two phenomena are natural reciprocals in the active and passive voices.

The development in the fish of a rhythmical system of motion responsive to the rhythm impressed upon it by its persistent environment and duly adjusted to it in pulse and force, is a

natural mode of neutralizing the current force and securing stability of position or motion against the current, as desired. Beyond question the form and the movement of the typical fish are admirably adapted to motion in static water and that has been thought a sufficient reason for the evolution of the form, and so possibly it may be, but fishes in static water have not as uniformly retained the attenuated spindle-like form and the extreme lateral flexibility as have those of running water. Among these latter it is rare that any great departure from the typical "lines" and from ample flexibility has taken place, while it is not uncommon in sea fishes. Among the latter not a few have lost both the typical form and the flexibility. The porcupine-fish, the sea-horse, the flounders, and many others are examples of such retrogressive evolution, which is doubtless advantageous to them within their special spheres in quiet waters, but would quite unfit them for life in a swift stream. And if the view be extended to include the low degenerate forms, like the Ascidians, that are by some authors classed as chordates, the statement finds further emphasis.

It is not difficult for the imagination to picture a lowly aggregate of animal cells, still plastic and indeterminate in organization, brought under the influence of a persistent current and caused to develop into determinate organization under its control, and hence to acquire, as its essential features, a spindle-like form, a lateral flexibility, and a set of longitudinal side-muscles adapted to rhythmical contractions, since these are but expressions of conformity and responsiveness to the shape and movement normally impressed by the controlling environment upon plastic bodies immersed in it. The necessity for a stiffened axial tract to resist the longitudinal contractions of the side muscles and thus to prevent shortening without seriously interfering with lateral flexibility, is obvious and is supplied by a notochord. Thus, by hypothesis, the primitive chordate form may be regarded as a specific response to the special environment that dominated the evolution of a previously indeterminate ancestral form.

That some primitive animal aggregate far back in pre-Cambrian time should have found refuge from marine persecution or competition in the sweet running water that entered the sea at so many points, and should have evolved on lines in strict conformity with the dominant force of its new environment does not seem improbable.

If such were the origin of the vertebrate type, its subsequent history and the peculiar phases of fossilization previously discussed are natural sequences.

Distribution from river to river would be slow but inevitable, without the aid of the bizarre agencies of water-fowl, whirlwinds, etc., sometimes appealed to in modern instances. The degradation of the land by streams involves inevitably much piracy, and at the stage of capture the two streams are united for a certain period; and for a still longer period they relieve each other of surplus waters in times of local floods which happen to affect one basin more than the other. Measured by the time requisite for fish migration, these periods of continuous and occasional communication are long. The event itself is, to be sure, infrequent. But in the history of a river basin, the piracy of some one or another of its numerous branches interlocking with the branches of neighboring basins is probably not especially rare. In the next geological period the number of piracies between the headwaters of the Mississippi, the St. Lawrence, the Hudson Bay system, and the Mackenzie will certainly not be few, and before the Cordilleran tract is base-leveled, it may safely be affirmed that piracies at many points will have furnished a migratory tract between the river systems of the interior and those of the Pacific.

Certain attitudes of the sea to the land develop lagoons and sounds behind spits, fringing inlands, and barrier tracts, and if the land be growing at the expense of the sea, the waters of these lagoons and sounds often become wholly cut off from the sea and so pass from the salt to the fresh condition, and thus afford a means of migration from river to river near their mouths. The attitudes which favor this kind of communication occur

inevitably in the changing relations of land and sea that attend the normal progress of geologic periods. Thus, on the head-waters by piracy and along the sea by lagoons, there are systematic sources of intercommunication by which fresh-water faunas may migrate from basin to basin and may thus occupy quite fully their appropriate domain without dependence upon accidental means or coast-wise communication by temporary entrance of the sea, which may be a resource in some cases. Measured by geologic periods, these means of migration are doubtless sufficiently frequent to be altogether adequate.

The extensions and the changes of domain thus provided to the hypothetical primitive chordate organism may be assumed to have sufficed for its expansion and differentiation through a long period without giving rise to any such degree of overcrowding as to force it to take to the sea for relief; and such intrusions upon the sea as occurred during this initial era may be regarded as individual and accidental.[1] If this be so, it may be inferred that even after the primitive chordates had become differentiated into the ancestral classes, and even into the main ordinal types of the fishes as we now know them paleontologically, and had also attained some measure of induration of parts, the preservation of these parts in the sea sediments would be rare; and this is in accord with experience.

In time, however, the streams must inevitably have become overstocked and a severe struggle for existence must have ensued attended by the acquisition of organs of attack and defense; and at length there must have been an irruption into the sea to avoid the greater enemies and the stronger competition at home. To such an irruption is assigned the remarkable apparition of agnathous and gnathous fishes at the close of the Silurian in varied type and clothed in full armor, expressing the urgency of the competition; though a notable part of the

[1] From early individuals that failed to hold their place in the streams for any reason, and succeeded in maintaining themselves in the sea to which they were carried, there may have sprung the lower chordate types like the ascidians and Balanoglossus, if they really belong to the vertebrate phylum.

apparition, it must be observed, was due to the exceptional preservation of the land record. Thereafter, by interpretation, the habitats of both the Agnatha and the Pisces were more general and varied, a portion taking permanently to the sea, and a portion remaining in the land waters, while a third portion migrated between the two. The well-known habit of many of the last to return to the swift inland streams to initiate each new generation is suggestive of ancestral conditions. The sharks, the hagfishes and many Teleostomes represent divisions that became permanently sea faring. The lung-fishes (Dipnoans), the old-type Crossopterygians, a part of the lampreys, and many others seem to have mainly adhered to the fresh water, at least their present representatives now frequent these waters, either exclusively or in the main. The fossil record of this latter group, throughout the later geologic ages, is well nigh as scant as that previous to the Devonian, and this would seem to be a very significant fact. The lampreys seem to have been ancestrally represented in the Devonian by the little *Palæospondylus gunni* recently found in beautiful preservation in the Achanarras quarry in North Scotland, where conditions for the preservation of fresh-water deposits were exceptionally good. After this single appearance the lamprey type was lost to sight until modern times revealed its probable descendants in the lamprey of our present waters. In like manner, the Dipnoans, after a notable record in the Devonian and Carboniferous periods, where fresh-water life was exceptionally preserved, nearly disappeared from the record, but are now found in three forms, one in each of the three southern continents, Africa, Australia, and South America. So, too, the singular Crossopterygians, though their deployment may have been wider, after a fine display in the Devonian and Carboniferous, passed into a decline in the early Mesozoic and disappeared in the Lias, but are now found in the fresh waters of Africa. Special interest attaches to the Dipnoans and Crossopterygians as the probable ancestors, or the nearest known kin to the ancestors of the amphibians, and through them, of all reptiles, birds, and mammals, because it

carries a certain measure of presumption that the amphibians were fresh-water derivations.

In this larger application of the interpretation herein suggested, the chordate phylum is made to be essentially from first to last a terrestrial race, whose main habitat was the land waters and the land itself, though still a race that sent its offshoots down to sea from time to time from the mid-Paleozoic onwards.

The large hypothetical element in the foregoing interpretation is sufficiently evident and needs neither word of caution nor apology. The problem at present admits of no other than hypothetical treatment. The discussion is merely the attempt of a geologist to interpret from the geologic side the imperfect data that bear obscurely on the habitat of the early vertebrates.

T. C. CHAMBERLIN.

THE BIOGENETIC LAW FROM THE STANDPOINT OF PALEONTOLOGY.

The interest of the paleontologist in embryology, and in ontogeny in general, lies wholly in the wish to know the origin and relationships of biologic groups; a scientific interpretation of ontogenic data in terms of phylogeny depends on the extent of preservation of the ancestral record in individual development. The broad statement has often been made that each animal gives in its own development an epitome of the history of its race. Because of the law of heredity, this statement would be true, and the record would be complete, if nothing had interfered with the normal course of things. But, in reality, so many secondary elements are introduced in development, that authorities are very much divided as to the value of ontogenic stages as records of race history.

There can be no doubt that students of postembryonic stages have been inclined to claim too much for the law of tachygenesis, while, on the other hand, students of embryology have been inclined to discredit it almost entirely, and to lay little stress on ontogenic stages as a recapitulation of phylogeny. The reason for this disagreement is not far to seek; it lies in the field and in the methods of research of the two groups of morphologists.

Types of development.—Leaving out of consideration the *Protozoa*, which come into being with the essential characteristics of the adults, there are, in the *Metazoa*, two types of development: (1) the *fœtal type*, in which the development takes place in the egg, or in the body of the parent, and the young animal comes into the world in form closely resembling the adult; (2) the *larval type*, in which the young animal comes out at an earlier stage of development, and reaches maturity only after considerable metamorphosis.

Secondary elements will be introduced in either type of development, and those variations that are favorable to the preservation of the species are likely to be perpetuated by heredity. Now in the fœtal type the most favorable variation consists in abbreviation, thus simplifying the development. Any characters that are useful in a free state, but not in a fœtal state, are liable to be lost. Thus in the fœtal type the tendency is toward loss of the record through omission of stages or obscuring them, for many organs that would be highly developed in mature forms, or in free larvæ, will be either suppressed or undifferentiated.

The vertebrates, most of the higher crustaceans, most land and fresh-water mollusks[1] have the fœtal type of development; and these embrace by far the larger part of animals whose ontogeny has been studied. It is not to be wondered at, then, that morphologists who deal exclusively with embryonic stages of these groups should be skeptical about the repetition of family history in individual development. Here many stages are omitted, and the rest so obscured and undifferentiated as to be unintelligible; and secondary characters, due to life in the egg or in the parent, are introduced, effacing what little meaning was left. Then, too, embryologists are often content to trace the animal but a little way toward perfection of development; they study the embryo until the cells begin to divide into groups indicating a beginning of organs, and call this studying ontogeny, when they have stopped before it could be told whether the animal was going to develop into fish, flesh, or fowl. To this sort of study is due the idea of "falsification of the record," a crime of which nature has not yet been guilty, although she at times may not, perhaps, have told the whole truth.

Primary and secondary larvæ.—If the way of the embryologist lies in stony places, that of the student of postembryonic stages is not much smoother; formidable obstacles meet him on every side, reducing his small stock of faith. At the very outset he is confronted by the difficulty that there are two distinct types of

[1] *Dreissensia*, a fresh-water pelecypod, which in very recent geologic time has immigrated from salt water, still goes through its larval development, like its marine relatives.

larvæ: (*a*) *primary larvæ*, such as are more or less modified from ancestral forms, and have continued to develop as free larvæ since the time when they constituted the adult forms; (*b*) *secondary larvæ*, such as have been introduced by cenogenesis into the ontogeny of species that formerly developed by the fœtal process. If ancestral characters have been retained in the egg, then these secondary larvæ may bear some palingenetic characters, and thus be hard to distinguish from primary larvæ; otherwise they will be entirely adaptive, or cenogenetic. A case in point is the development of most insects, whose larval stages are supposed to be largely secondary. Study of individual development in a group of this sort can throw little light on phylogeny.

The student of larval stages must confine himself to the primary sort, if he would correlate them with ancestral genera. The development of the cœlenterates, echinoderms, brachiopods, most mollusks, and the lower crustaceans is direct; thus larval stages of these groups may be bearers, to a greater or less degree, of ancestral characters. But since the free larvæ of even these groups are exposed to natural selection, secondary or cenogenetic characters will be introduced, obscuring the resemblance to ancestral forms; also characters that in the adult ancestral form were functional and fully developed may, in the representative larval stage of the descendant, be so little differentiated as to be unrecognizable.

But how can the morphologist who deals entirely with living species know whether a character is primary, and repeated by palingenesis in the larval history of the descendant, or whether it is secondary, and introduced by cenogenesis into that history? The answer to this lies wholly within the domain of paleontology, for only by finding a stage of growth represented by an ancestral form can the morphologist know that the characters of that stage are ancestral, and not secondary. Larval stages which may be the bearers of ancestral characters must then be compared with the adults of their predecessors, and the paleontologic record must be invoked as a final resort — the court from which there is no appeal.

And this was exactly the method used by Louis Agassiz, who first applied the law of acceleration of development to the study of systematic zoölogy, although it never had much influence on biologic investigation until the palentologic studies of Hyatt in the invertebrates and Cope in the vertebrates placed the law on a sound basis. It was reserved for Alpheus Hyatt to formulate the law and to strengthen theory with practical examples based on study of cephalopods. In his later papers Professor Hyatt[1] has given a more exact and comprehensive definition of the law of acceleration or *tachygenesis:* "All modifications and variations in progressive series tend to appear first in the adolescent or adult stages of growth, and then to be inherited in successive descendants at earlier and earlier stages according to the law of acceleration, until they either become embryonic or are crowded out of the organization and replaced in the development by characteristics of later origin." A still more definite statement by the same author is the following: "The substages of development in ontogeny are the bearers of distal ancestral characters in inverse proportion and of proximal ancestral characters in direct proportion to their removal in time and position from the protoconch, or last embryonic stage."[2]

To insure trustworthy results in verifying this law, the investigator must have groups in which the larvæ are primary and reproduce ancestral characters; in which the living and the fossil are classified on the same basis; of which we have preserved a nearly complete geologic record, and of which material is available for the study of fossil ontogeny as a check on the living. Such groups are especially represented among the *Cœlenterata*, the *Echinodermata*, the *Brachiopoda*, and the *Pelecypoda* and *Cephalopoda* among the mollusks.

Unequal acceleration.— Now, when the morphologist has settled the fact that primary larval stages do actually reproduce, more or less vaguely, characters that existed in the adult forefathers of the generation he is at work on, his troubles are even

[1] Genesis of the Arietidae, p. 9.

[2] Philogeny of an Acquired Characteristic, p. 405.

then not yet ended; for the characters do not necessarily appear in the ontogeny of the descendant in the same association in which they occurred in the ancestor. A character useful to the immature form will have a tendency to be inherited at an earlier age than those useful only to the adult, and so by unequal acceleration of development the parallel between ontogeny and phylogeny is broken. It was once thought that the *Nauplius* larva of the crustaceans was a mature genus, then it was thought to be a larval representative of the extinct radicle of the Crustacea; later still, many morphologists have concluded that the *Nauplius*, while it bears many crustacean characters, still retains too many annelid characters to represent the radicle of the group; it is a typical crustacean larva, but not a representative of the primitive crustacean, and the two sets of characters are thrown together by unequal acceleration. Beecher has shown the same thing in the spiny larvæ of *Acidaspis* and *Arges*, where in the protaspis of these genera the spines characteristic of the adults appear, contrary to usage among the trilobites, in which larval stages are usually smooth. Thus before these animals have assumed characters that would identify them undoubtedly with trilobites they have assumed those most characteristic of their own genera. Jackson has shown that in the larvæ of the *Pectinidæ* unequal acceleration may associate characters that were not synchronous in race history. F. Bernard has recently shown that the prodissoconch of pelecypods is sometimes striated and ribbed, characters that could not have belonged to the primitive pelecypod.

If unequal acceleration causes confusion in the phylembryonic stages, the difficulty is much greater in the larval and adolescent periods, where the shortness of the time of development causes throwing together of characters that were not contemporaneous in the ancestors, and where the small size and general habits prevent differentiation of organs that in the correlative adult forms were highly developed, thus obscuring and even destroying the exactness of the parallelism. Two species of *Placenticeras*, of which the ontogeny has been recently studied

by the writer, must have descended not only from the same perisphinctoid family, but also from the same species of *Hoplites;* and thus, if the parallel were at all exact, they should be alike in the late adolescent stages when they begin to show their generic characters. This, however, is not the case, for they are quite different throughout the cosmoceran stage, and back almost to the end of the larval period, where the transition from goniatite to ammonite took place. If this were interpreted without taking account of unequal acceleration, it would seem that the differentiation of the two species took place back in the Trias, and that different ægoceran forms were the remote ancestors of the two species, which we know could not have been the case.

The writer has recently worked out the ontogeny of two very nearly related species of *Schlœnbachia*, one of which, in its larval period, reproduces very exactly a *Paralegoceras* stage, while the other does not ; the latter species has, however, all the paralegoceran characters, but associated with others that this genus never had, but which belonged to later descendants of this genus. There can be here no question of the veracity of nature in keeping the record, the difficulty lies in deciphering it. So it is not to be expected that any one species would give in plain terms the complete phylogeny of a genus, for stages that are plainly differentiated in one will be obscured in another, and only by studying the ontogeny of a number of species of one genus can the morphologist hope to get a complete history. It is still less to be expected that two separate genera, even when closely related, should tell their story in exactly the same terms, for stages that are emphasized in the ontogeny of the one are obscured and possibly even omitted in the other. And in this case the unequal acceleration goes much farther than with closely connected species. In a comparative study of *Lytoceras* and *Phylloceras* the writer[1] has recently shown how rapid this divergence is, and has drawn the conclusion that unequal

[1] The Development of *Lytoceras* and *Phylloceras*. Proc. Calif. Acad. Sci., Third Ser. Geol., Vol. I, No. 4, 1898.

acceleration would account for a large part of the differentiation observed in successive geologic generations.

Retardation.—Another factor that makes it difficult to correlate ontogeny and phylogeny is *retardation* of development. Cope first recognized the principle, but in his writings confused it with unequal acceleration, and since his reasoning was purely theoretical the idea has never gained much foothold in biologic philosophy. Cope's[1] statement of the theory is as follows: "The acceleration in the assumption of a character, progressing more rapidly than the same in another character, must soon produce, in a type whose stages were once the exact parallel of a permanent lower form, the condition of inexact parallelism. As all the more comprehensive groups present this relation to each other, we are compelled to believe that *acceleration* has been the principle of their successive evolution during the long ages of geologic time. Each type has, however, its day of supremacy and perfection of organism, and a retrogression in these respects has succeeded. This has, no doubt, followed a law the reverse of acceleration, which has been called *retardation.* By the increasing slowness of the growth of the individuals of a genus, and later assumption of the characters of the latter, they would be successively lost." This statement of Cope might apply equally well to unequal acceleration of characters, but in another part of this same work he gives a clearer statement: "Where characters which appear latest in embryonic history are lost, we have simple retardation, that is, the animal in successive generations fails to grow up to the highest point of completion, falling further and further back, thus presenting an increasingly slower growth in the special direction in question."[2]

These remarks of Cope were based on abstract reasoning, but it is possible to bring up some striking cases in support of the theory, notably among the brachiopods. Fischer and Oehlert[3] have shown that while brachiopods go through many metamorphoses in individual evolution, and while each species

[1] Origin of the Fittest, p. 142. [2] Op. cit., p. 13.

[3] Brachiopodes, Mission Scientif du Cap Horn, p. 50–60.

is usually constant in the stages it goes through, it often happens that the individual is arrested in development, never reaching the full generic development of the mature stage. The individual then begins to reproduce its kind before maturity is reached, and tends to give rise to a stock that never reaches the full generic evolution of its ancestors. Dr. C. E. Beecher has well described this: "In each line of progression in the Terebratellidæ the acceleration of the period of reproduction, by influence of environment, threw off genera which did not go through the complete series of metamorphoses, but are otherwise fully adult, and even may show reversional tendencies due to old age; so that nearly every stage passed through by the higher genera has a fixed representative in a lower genus. Moreover, the lower genera are not merely equivalent to, or in exact parallelism with, the early stages of the higher, but they express a permanent type of structure, so far as these genera are concerned, and after reaching maturity do not show a tendency to attain higher phases of development, but thicken the shell and cardinal process, absorb the deltidial plates, and exhibit all the evidences of senility.[1]

If, then, the morphologist tries to study the race history in one of these species thus arrested in development, he cannot read the whole story, for the individual ontogeny will not recapitulate the higher stages lost by retardation.

Another remarkable case is that of the so-called "ceratites" of the Cretaceous. While there have been no goniatites since the Paleozoic, and no ceratites since the Trias, there are found among the ammonites of the Cretaceous some with septa of simple goniatitic character, and others with septa like those of the genuine ceratites. Now since the line of descent is broken, and there is no possibility for a continuous line of these ancient primitive forms to have bridged over the great gap from the Trias to the Upper Cretaceous, we must explain this either by reversion or in some other way. But it is not a simple case of reversion, for, as has been pointed out by several writers,

[1] Amer. Nat., Vol. XXVII, 1893, p. 603.

Douvillé, Nicklès, and others, the septum of adolescent ammonites of this group is not more complex, but really less so, than that of adults, although they are derived from Jurassic genera with complex septa. Thus Douvillé derives the group *Placenticeras-Sphenodiscus* from *Hoplites;* the Pulchellidæ, composed of *Pulchellia*, *Neolobites*, and *Tissotia*, he derives from *Oppelia* of the Jura. Since in each case the ancestral forms are more complex than the descendants, the reduction in complexity of generic evolution can be explained only by retardation or arrested development. F. Bernard has in addition pointed out the fact that the adult of *Pulchellia* is like the adolescent stage of the ancestral *Oppelia.* Now if we define the law of acceleration of development to mean that in a progressive series the young of the descendants correspond to the adults of their more remote ancestors, we find that this does not apply to a retrogressive (retarded) series. In this latter case we must restate the law as follows: the adults of descendants correspond to the young of their more remote ancestors, the higher generic stages to which these ancestors attained having been dropped away by successive retardation or arrested development. The retarded series themselves may become the radicals of new stocks, and so we may have cases where the ontogeny of any one species or genus can never give the full history of the race.

Groups available for correlation.—We see then that the student of morphogeny of animals has to be on his guard, first against the loss of generic stages during the period while the animal is in the egg; then against the introduction of secondary larval stages when the ancestors lacked them; then against the introduction of secondary characters due to adaptation; then against unequal acceleration, bringing together in the ontogeny of the descendant, characters that occurred in separate generations of ancestors; and lastly, against retardation, by which the form never reaches the full generic evolution of its ancestors, and where, if a new series starts out from the retarded form, the complete family history is not recorded in ontogeny.

Is it to be wondered at, then, that the student of morphology becomes a sceptic, or even a rank unbeliever with regard to the value of ontogenic stages as records of history? It is only to be expected that the biologist, especially one that deals almost exclusively with living species, should be inclined to discredit the law of tachygenesis, and to believe that there is such an inextricable muddle of omissions, secondarily introduced characters, and unequal acceleration of those actually repeated, that the record is wholly untrustworthy, or at least illegible. And yet there are so many species and genera in the various groups of invertebrates whose ontogeny is simple, progressive and fairly complete, and whose stages of growth are almost exact repetitions of successive antecedent genera, that it would be impossible to find a student of the morphogeny of the brachiopods, the marine mollusks, or the lower crustaceans, that does not believe implicitly in the value of larval stages of these groups as records of their family history. And this is especially true of the paleobiologists, who regard it of little importance whether the animal under investigation died yesterday, during the flood, or during the Paleozoic era, whether it is preserved in alcohol or in a more permanent museum in the bosom of mother earth; they recognize the fact that the life-history of a Cambrian trilobite has as much bearing on modern biology as does the history of the living crayfish, and that the laws that govern the rise and decline of organisms were just as true then as now.

Not all groups are equally useful to the student of morphogeny, but in each of the lower subkingdoms there are genera of which the ontogeny has been studied and correlated in no uncertain terms with the history of the race. The testimony of these various groups is so uniform, notwithstanding the fact of its having been gathered by men of different beliefs, that its value cannot be doubted. It is also noteworthy that in the higher groups, such as cephalopods and crustaceans, the evidence and the correlations are much more decided.

Cœlenterata.—It has been shown by Dr. C. E. Beecher that the young stages of the Favositidæ correspond to *Aulopora*, or to some other similar unspecialized genus. This same conclusion has been reached by Dr. G. H. Girty based on a study of the ontogeny of *Favosites*, *Syringopora*, and other tabulate corals, all of which are shown to go through an *Aulopora* stage of growth.

Echinodermata.—The only crinoid of which the ontogeny is known is *Antedon*, which has been shown by Sir Wyville Thomson to go through successively stages corresponding to the *Ichthyocrinoidea* of the Paleozoic, and *Pentacrinus* of the Mesozoic, before it becomes free swimming and takes on the characters of *Antedon*.

Dr. R. T. Jackson has been able to prove even in the Paleozoic sea-urchins the possibility of correlating growth stages with phylogeny, in spite of the great difficulties due to resorption of plates, and change of form.

Brachiopoda.—According to Beecher all brachiopods go through a primitive protegulum stage, correlative with the supposed ancestor of the class, although *Paterina*, which was formerly supposed to be this radicle, has been shown to be much more highly specialized than the protegulum stage. The later stages of growth of this class are capable of even more remarkable correlation, as has been shown by Beecher in a number of papers, where every stage of growth is distinctly homologous with well known pre-existing genera; and these same successive genera show a gradual transition in the adults.

Even among the Paleozoic spire-bearers (*Helicopegmata*), this holds good, for Beecher and Schuchert have demonstrated that the early stages of this group are homologous with the terebratuloids (*Ancylobrachia*), aud more especially with the Paleozoic genus *Centronella*, the most primitive of the loop-bearing brachiopods.

Mollusca.—Jackson's correlations of the stages of growth of pelecypods with their race history have already become classic; according to these, every pelecypod begins its bivalve state with

a nuculoid stage, homologous with the primitive radicle of the group. Every *Pecten* goes through stages successively correlative with a nuculoid, *Rhombopteria*, *Pterinopecten* and *Aviculopecten* before it reaches maturity, each stage appearing in the order of the ancestral genus. Even the greatly modified oyster shows its kinship with this group by its nuculoid and *Rhombopteria* stages.

The researches of Branco have made it clear that each group of cephalopods has its typical phylembryo, in a general way correlative with the radicle of the group, and that the later stages may be compared very accurately with ancestral families and genera. The way for this was opened by Hyatt's memoirs on the ontogeny of the ammonites, in which it was shown that in each perfect adult ammonite shell the complete individual ontogeny is recorded. By using this same method Karpinsky has been able to correlate the ontogeny of *Medlicottia* and *Pronorites* with successive ancestral forms, from *Anarcestes*, *Ibergiceras*, *Paraprolecanites*, up to the adult stage.

By the ontogenic method Buckman has been able to get at a sound basis of classification of the Jurassic ammonites, and to correlate the growth stages of many of these with their race history. Although his conclusions as to the systematic position of many of these genera do not agree with the ideas commonly accepted concerning them, it must not be forgotten that these conclusions are based, not merely on ontogenic study alone, but also on the gradual transitions of a series of adults. This is the strongest confirmation that any phylogenic research could ever have.

Crustacea. — Among the most convincing morphogenic researches are Beecher's studies in the ontogeny of the trilobites, all of which are shown to go through a phylembryonic *protaspis* stage, correlative with the primitive crustacean, and similar to the protonauplius of the less specialized living crustaceans. Here, too, it was demonstrated that the larval and adolescent stages of Devonian, Silurian, and even Cambrian trilobites may be correlated with the adults of preëxisting

genera, giving the basis of a natural, or biogenetic, classification of this extinct group.

Many more cases might be added to those cited here, but surely no additional evidence is needed, for all this points in the same direction, whether gathered by believers in or opponents of the theory of evolution. To this latter class belong the evidence brought forward by Barrande in the ontogeny of trilobites, and by Agassiz in the law of recapitulation or acceleration of development. Each of these naturalists used unhesitatingly the method that in the hands of Hyatt and his followers has been so fruitful of results.

JAMES PERRIN SMITH.

THE LOCAL ORIGIN OF GLACIAL DRIFT

Normal till is made up predominantly of materials which have not been transported many miles, though some of the minor constituents have often come greater distances. Roughly speaking, the more distant the contributing rock formation, the less its contribution to the till at any given point. There are apparent exceptions to this generalization, but they are chiefly the result either of the unequal exposures of the several formations contributing to the drift, or to their unequal resistance to abrasion.

Locally, the constituents of the drift of distant origin, drop almost to zero. This is true both of drift composed chiefly of clay, and of that which contains abundant coarse material. In extreme cases, stony till is chiefly composed of blocks of rocks that have been moved but little from their original positions. They have been displaced and the clay or sand (the finer portions of the till) have been mixed with them, so that the two sorts of material appear to have been kneaded together. In such cases the rock masses are angular and rough, and frequently increase in size and number from the top of the till to its base. At the base they may be so abundant as to nearly exclude all other constituents. If the surface of the rock be much broken, and its uppermost layers disrupted and crumpled, as is sometimes the case, it may be difficult to say where the line between the bottom of the till and the surface of the underlying rock is to be drawn. Where the rock which gave origin to the drift was not well suited to making bowlders, the comminution of the material gave rise to clayey or earthy matter, as really though less obviously local in origin, as if it had remained in larger pieces. Considering the area of the continental ice-sheets, and the distance which much of the ice traveled, the small proportion of the drift which has come from distant

sources has always seemed a stumbling block to those who are familiar with the facts, but not with their meaning.

In Fig. 1, *a* represents the center of the sector of an ice-cap, and *b d* its circumference. The areas marked 1, 2, 3, and 4 represent successive and equally wide belts of rock of equal resistance and like topography. The center of movement is assumed to be at *a*. When the ice has advanced from *a* to *b d* the deposit of till made at that point is made by ice which, in so far as it has moved from the center, has passed over formations 1 to 4 in succession. In such situations the drift is normally found to contain more material from 4 than from 3, more from 3 than from 2, and more from 2 than from 1.

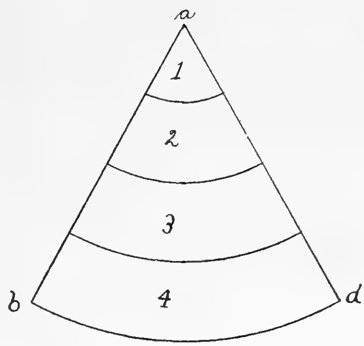


FIG. 1.

It will be understood that if the width of the exposures of the several formations were unequal, or if the several formations were of unequal resistance, the case might be very different. It is also clear that the topography of the several belts will influence the amounts of their contributions, and in view, first, of the varying widths of the various belts of rock passed over by the ice, second, of their varying topographies, and third, of their varying degrees of resistance, many exceptions may arise to the generalization that the contributions of various formations to the till of any locality are in inverse proportion to their distances from the point concerned.

The explanation of the markedly local character of the drift appears to involve several considerations. Fig. 1 illustrates one point involved. Suppose the ice passing over the formations 1, 2, 3, and 4, successively, gathers material with equal facility from each of them. By the time the ice from 1 has spread over 2, the average thickness of the basal layer of drift derived from 1, supposing none of it to have been deposited, would have been reduced to one third its original thickness, since the area of 2 is

three times as great as that of 1. By the time the same ice has spread over 3, the basal layer of drift derived from 1 will have been reduced to one fifth its original thickness, since the area of 3 is five times the area of 1. Still supposing none of it to have been deposited when 4 has been overspread, the thickness of the drift derived from 1 when the ice has covered 4, will be but one seventh of that which it possessed over 1. Even supposing all the drift from 1 to be carried to 4 over the intervening areas, it is thus seen that at such a point as *c*, the amount of distant material should be relatively small. If the ice keeps an equal amount of drift in and beneath itself by gathering enough new material to counterbalance the thinning of that previously held, the till at *c* should be made up as follows:

From formation 1	$\frac{1}{16}$
From formation 2	$\frac{3}{16}$
From formation 3	$\frac{5}{16}$
From formation 4	$\frac{7}{16}$

Thus the spread of the ice will tend constantly to decrease the proportion of basal drift derived from any formation, once that formation is passed.

Since some of the drift derived from 1 would doubtless be lodged as the ice advanced over formation 2, the average thickness of that carried from 1 to 3 will be correspondingly diminished beyond the figure given ($\frac{1}{5}$ of that over 1). Since more of the material from 1 will in all probability be deposited on 3, as the ice advances to 4, the figures given for the thickness on 4 of drift derived from 1 ($\frac{1}{7}$ of that on 1), will need to be still further reduced, and that by a larger amount than that to which the $\frac{1}{5}$ was subject. In view of the continual lodgment of drift, it will be seen that the series of fractions given above, namely $\frac{1}{16}$, $\frac{3}{16}$, $\frac{5}{16}$, and $\frac{7}{16}$ will need to be changed by some undetermined amount, but so that the extremes well be farther apart, and the differences between successive members greater. If $\frac{3}{4}$ of the drift carried from 1, were deposited on 2, 3, and 4, and $\frac{1}{2}$ of that from 2 on 3 and 4, and $\frac{1}{4}$ of that from 3 on 4, the last member of the preceding series of fractions would be increased at the

expense of others. The preceding series would then be brought to some such terms as the following:

From formation 1 - - - - - -	$\frac{1}{64} = 1\frac{1}{2}\% +$
From formation 2 - - - -	$\frac{4}{64} = 6\ \% +$
From formation 3 - - - - - -	$\frac{15}{64} = 23\ \% +$
From formation 4 - - - -	$\frac{44}{64} = 69\ \% +$

Thus the constant tendency of the drift to lodge, after being once started, tends still further to diminish the quantity of drift from any formation after the formation is passed.

The effectiveness of the tendency to lodgment of drift near its source is dependent on several conditions. One of them is the rate and steadiness of movement, and another the topography of the surface. The edge of the ice is not believed to have moved forward at equal rates, either during its advance or during its retreat. Whenever the edge of the ice, after a given advance, remained approximately constant in position for a period of years, all the drift brought to the edge of the ice during the halt accumulates beneath it. It presently accumulates in sufficient quantity to form a submarginal ridge or barrier, and when the ice is again affected by movement sufficient to carry its edge farther forward, it is obliged to override or carry forward this submarginal accumulation. Judging from the phenomena of North Greenland, such material was more largely overriden than urged along. Thus the drift gathered toward the center of the ice field is lodged in exceptional quantity wherever the edge of the ice was for a time nearly stationary, and the ice which passed on over the drift which was lodged proceeded to gather a new load made up chiefly of material derived from the surface outside the position of the preceding halt. This tends to emphasize the local tacies of the drift.

These considerations in themselves would be quite sufficient, as the last set of fractions shows, to explain the great predominance of relatively local material in the drift of any given region, but other factors serve to emphasize the point still further.

The top of the ice-sheet moves forward faster than the bottom. One reason for this is that the lower part, which is more

fully charged with débris, becomes more rigid, while the more mobile part above moves on over it. If in Fig. 2 the several curves *a*, *b*, *c*, *d* represent the profiles of the ice in successive stages of advance, the ice which is at the bottom, and which is eroding formation 4, may not be the ice which was at the bottom over 2, but instead ice which was well up from the bottom over this formation. In this case it is clear that the ice working on 4 has relatively little material derived from 2. At first thought it might seem that it should have nothing, but this conclusion does not follow. As the relatively débris-free ice above moves

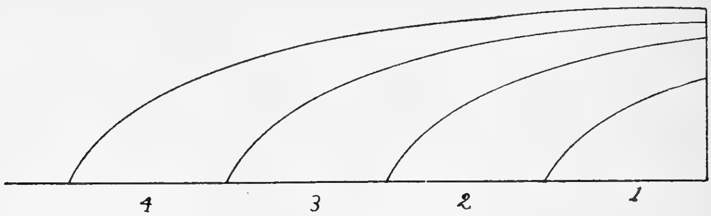


FIG. 2.

over the relatively heavily débris-charged ice below, it drags along some of the material lying in the upper part of the débris zone. Thus as the ice moves over 4, the upper part, being in faster motion, will be carrying along some of that derived from 2 and and even from 1, so that at least a small amount of the material from these formations is to be expected in the bottom of the ice over 4. Nevertheless, the tendency is all along to leave the material already carried by the ice in the rear, and to let the advancing edge acquire its own load, primarily from the successive formations invaded. The result of differential movement, the faster movement being above, is to diminish still further the proportion of the material in the drift at any given point which was derived from distant sources. Because of the effects of differential movement therefore, the last series of fractions would need to be still further changed, so that the first member would be smaller and the last larger.

The topography over which the ice had moved would also influence the proportions of material of near and distant origin.

If the ice passing over 2 encounters a rough topography, so that drift was introduced into the ice far above its base, a large amount of matter from 2 would go forward in the more rapidly moving upper part, and be found in the ice, and finally in the drift, over 4, or beyond.

There is at least one other factor involved. Much of the ice which passes over 4 (Fig. 2) never passed over 1, but accumulated on 2, 3, and 4. This does not preclude the passage of some ice from 1 to 4, but simply means that much of the ice at 4 has never had a chance to work on 1. The idea involved may be gathered from Fig. 3. Let the lines *a*, *b*, and

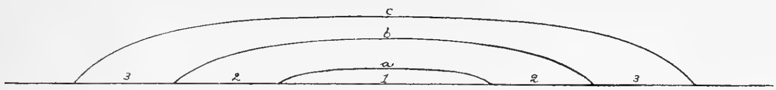


FIG. 3.

c, respectively, represent the successive profiles of a growing ice-sheet. Much of the upper part of the ice, the profile, of which is *c*, accumulated over areas 2 and 3 and did not come from 1, as already stated. This upper ice which never worked on 1, is moving more rapidly than the ice at lower levels which came in part from 1. Furthermore the conditions of snowfall and movement are such as to develop a high marginal and a low central gradient. The excessive marginal snowfall, for such was probably the condition, will in some sense check movement from the center, and make the marginal portion of the field the effective dynamic center of movement. The origin of much of the ice far from the center of the ice-sheet, where it had no chance to work on rock formations near the center, tended still further to make the material carried and deposited by the ice at any point of local origin. The effect of this factor is to still further differentiate the fractions of the preceding series.

When the spread of the ice, the constant tendency to lodgment of drift in transit, the differential movement, and the marginal origin of much of the ice are all considered, it is probably true that the fractions given on pp. 428, 429 give much

too large a percentage of widely transported material in the drift occupying such a position as that to which the fractions are applied. Taken together, too, these factors would seem to explain adequately the local character of the material of the till.

R. D. S.

SUMMARIES OF CURRENT NORTH AMERICAN PRE-CAMBRIAN LITERATURE.

(*Continued from p. 425, Vol. VII.*)

WALCOTT[1] discusses pre-Cambrian fossiliferous formations of North America. In two cases only have fossils of undoubted organic origin been shown to occur in formations of reasonably certain pre-Cambrian age, namely, the Grand Canyon of Arizona, and the Belt terrane of Montana. The Etcheminian terrane of New Brunswick and Newfoundland is doubtfully a third instance.

A brief account is given of the stratigraphy of each of the areas of pre-Cambrian sedimentary rocks. No new points appear except in the description of the Belt terrane of Montana; the account of the Belt terrane is therefore the only one summarized with reference to stratigraphy.

The Belt terrane of Montana covers an area of more than 6000 square miles in central Montana. The principal beds of the terrane are as follows:

Marsh shales	300 feet.
Helena limestone	2,400 "
Empire shales	600 "
Spokane shales	1,500 "
Greyson shales	3,000 "
Newland limestone	2,000 "
Chamberlin shales	1,500 "
Neihart quartzite and sandstone	700 "
	12,000 feet.

Throughout the area the Belt terrane is overlain unconformably by middle Cambrian rocks (Flathead). The Cambrian rocks rest on various members of the Belt series, and in places the Belt terrane is entirely wanting, the Cambrian resting directly on the Archean schists. In such cases, moreover, the character of the Belt beds indicates that the Cambrian overlaps the Belt series. The base of the Cambrian is not markedly conglomeratic. At most of the outcrops where the lower

[1] Pre-Cambrian Fossiliferous Formations, by CHARLES D. WALCOTT: Bull. Geol. Soc. Am., Vol. X, 1899, pp. 199–244.

beds of the Flathead (Cambrian) sandstone come in contact with the Belt rocks the dip and strike of the two are usually conformable, so far as can be determined by measurement. This holds good all around the great Belt Mountain uplift. It is only when contacts are examined in detail, as near Helena, that the minor unconformities are discovered, and only when comparisons are made between sections at some distance from one another that the extent of the unconformity becomes apparent. In general from 3000 to 4000 feet of the upper strata of the Belt terrane were removed by erosion in late Algonkian time before the Middle Cambrian was deposited. It is believed that an unconformity of this extent is sufficient to explain the absence of Lower Cambrian rocks and fossils and to warrant the placing of the Belt terrane in the Algonkian system.

The fossils thus far found in the Belt terrane occur in the Greyson shales at a horizon approximately 7700 feet beneath the summit of the Belt terrane at its maximum development. The fauna includes four species of annelid trails and a variety that appears to have been made by a minute mollusk or crustacean. There also occur in the same shales thousands of fragments of one or more genera of crustaceans.

Grand Canyon series.—The fossils of the Grand Canyon Upper Cambrian series consist of specimens of a small discinoid shell found in the upper division of the Chuar terrane, and a Stromatopora-like form from the upper portion of the lower division and the central portion of the upper division of the Chuar. Other obscure forms appear whose identification is doubtful.

In New Brunswick certain rocks below the middle Cambrian, according to Matthew, contain fossils which may be pre-Cambrian. (See summary of Matthew's articles, following, p. 435, and of later article by Walcott, p. 436.)

The Llano series of Texas is a series of alternating sandy shales, sandstone, and limestone, very similar to those of the Grand Canyon pre-Cambrian series and overlain by a middle Cambrian sandstone similar to the Tonto sandstone of the Grand Canyon district. No fossils have been found in these rocks, although no systematic search has been made.

The Avalon series of Newfoundland includes all the pre-Cambrian sedimentary rocks of that area. Overlying them are Cambrian strata carrying olenellus fauna.

The Aspidella of the Momable slates is probably of organic origin, but it may be questioned. Other reported forms are inaccessible for study.

In the Lake Superior country markings have been reported as found in the Huronian iron formation of the Menominee iron district of Michigan. An examination of the specimens indicates that they probably are from the basal detrital material of the Cambrian which rests upon the Huronian iron formation. In the Animikie rocks of the Lake Superior region the evidence of life consists of the presence of graphitic material in the slates and of a supposed fossil mentioned by Mr. G. F. Matthew. In the Minnesota quartzite of the Upper Huronian series lingula-like forms and an obscure trilobitic-looking impression are described by Winchell. The latter has been examined and the conclusion is reached that it is of inorganic origin. As to the lingula forms, the weight of evidence is in favor of their being small flattened concretions.

In general, the reported discoveries of fossils in the crystalline rocks of the Algonkian are as yet too problematic to be of value to the geologist and paleontologist. Apparently the best that can be said of Eozóon and allied forms is that they may be of organic origin, but it is not yet proved. The same appears to be true of the supposed fossil sponges described by Mr. G. F. Matthew from the Laurentian rocks of New Brunswick. The graphite in pre-Cambrian forms is probably in many cases of organic origin, but of the character of the life we know nothing.

Palaeotrochis formerly referred to as a pre-Paleozoic coral is determined by Professor J. A. Holmes and J. S. Diller as of inorganic origin.

Matthew[1] describes a Paleozoic terrane beneath the Cambrian in St. Johns and Kings counties, New Brunswick, on Cape Breton, and near Smith Sound, Newfoundland. This terrane is unconformably below Cambrian strata bearing paradoxides and protolenus fauna, and is given the name *Etcheminian*. The faunal features as distinguished

[1] A Paleozoic Terrane Beneath the Cambrian: Annals N. Y. Acad. Sci., Vol. XII, No. 2, 1899, pp. 41–56.

Preliminary Notice of the Etcheminian Fauna of Newfoundland: Bull. Nat. Hist. Soc., New Brunswick, XVIII, Vol. IV, 1899, pp. 189–197.

Preliminary Notice of the Etcheminian Fauna of Cape Breton: Bull. Nat. Hist. Soc., New Brunswick, XVIII, Vol. IV, 1899, pp. 198–208.

The Etcheminian Fauna of Smith Sound, Newfoundland: Trans. Roy. Soc. of Canada, 2d ser., 1899, Vol. V, sec. 4, pp. 97–119.

from the Cambrian are the great preponderance of tube worms, absence or rarity of trilobites, minuteness of the gasteropods, except Patellidae, minuteness of the brachiopods, and the minuteness of the crustaceans.

Walcott[1] believes the *Etcheminian* terrane of New Brunswick and Newfoundland called pre-Cambrian by Matthew to be of Lower Cambrian age. His evidence is:

1. That the Olenellus fauna in Newfoundland occurs 420 feet beneath the Paradoxides fauna, in the heart of the Lower Cambrian "Etcheminian."

2. That fragments of the fauna are found 460–480 feet below the Protolenus fauna in the "Etcheminian" of the Hanford Brook section of New Brunswick.

3. That in the undisturbed, unbroken Highland Range section of Nevada the Olenellus fauna is 4450 feet below the Upper Cambrian fauna, and that the Olenoides (Dorypyge fauna of Matthew) is 3000 feet below the horizon of the Upper Cambrian fauna and 1450 feet above the horizon of the *Olenellus gilberti* fauna.

4. That in the southern Appalachians the Olenellus fauna occurs more than 7000 feet below the highest Cambrian fauna known in that region, and fully 2000 feet below a typical Olenoides fauna.

Matthew[2] makes rejoinder to Mr. Walcott's discussion of the age of the Etcheminian terrane. He argues that Mr. Walcott depends chiefly upon the presence of Coleoloides typicalis as showing the presence of the Olenellus fauna; that this form is not always distinguishable from Hyolithellus micans, a problematical fossil probably of the tube worms, which, with the brachiopods, is the most striking of the fossils of the lower (Etcheminian) terrane. Moreover, the particular form of Olenellus which Mr. Walcott has found is the Olenellus bröggeri, rather than the Olenellus thompsoni, the original Olenellus. Olenellus thompsoni is supposed to occur above the Olenellus bröggeri, yet the Protolenus and Paradoxides faunas follow in regular succession to the fauna of the Olenellus bröggeri. The question is asked: Where is the fauna of Olenellus thompsoni? Its absence is supposedly taken as evidence of the presence of the unconformity held by Matthew.

[1] Lower Cambrian Terrane in the Atlantic Province, by C. D. WALCOTT: Proc. Washington Acad. Sci., Vol. I, 1899, pp. 301–339.

[2] Mr. Walcott's View of the Etcheminian, by G. F. MATTHEW: Am. Geol., Vol. XXV, 1900, pp. 255–258.

Emerson[1] describes the Algonkian rocks occurring in the southwestern corner of the Holyoke quadrangle in Massachusetts and in the area to the west. These are gneisses and limestones making up a series called the Washington gneiss. They are of sedimentary origin with the possible exception of the hornblende-gneiss of East Lee.

In general in western Massachusetts the Washington gneiss appears in oval areas surrounded by younger strata, the line of these ovals extending south from the Hoosac Tunnel along the crest of the Green Mountain plateau. The gneiss enters the Holyoke quadrangle at the southwest corner and runs up across the town of Tolland, narrowing to a point near Black Pond.

Woodworth[2] describes the Algonkian rocks in the lower portion of the Blackstone Valley and west of Providence, R. I., near the western margin of the Narragansett basin. From the typical development of the Algonkian rocks along the Blackstone River between Woonsocket and Pautucket, they are called the Blackstone series. This series is divided into the Cumberland quartzites; the Ashton schists, representing the finer sediments succeeding the deposition and partial erosion of the Cumberland quartzites, and in part probably igneous in origin; and the Smithfield limestone, apparently of sedimentary origin. As yet no facts have been discovered to show whether the limestones are of the same age or newer than the Ashton schists. The rocks of the Blackstone series are separated and penetrated by granitic intrusions or batholites.

The Blackstone series is assigned to the Algonkian because of the difference in metamorphism of the Blackstone series and Lower Cambrian strata, bearing Olenellus fauna, in North Attleboro. The Cambrian strata are little altered and lie in close proximity to the granite. Four miles west the Blackstone series is infolded with a similar granite and much altered.

Kemp[3] gives a petrographical account of the granites of the

[1] B. K. EMERSON: Geology of Old Hampshire County, Massachusetts, comprising Franklin, Hampshire, and Hampden Counties: Mon. U. S. Geol. Surv., No. 29, 1898, pp. 19–30. With geological map. This covers the area of the Holyoke quadrangle and in addition a narrow area to the north and east.

Holyoke folio, Massachusetts-Connecticut: Geol. Atlas of the U. S., No. 50, 1898.

[2] Geology of the Narragansett Basin, Part 2, by J. B. WOODWORTH: Mon. U. S. Geol. Surv., No. 33, 1899, pp. 104–118. With geological map.

[3] Granites of Southern Rhode Island and Connecticut, with Observations on Atlantic Coast Granites in General, by J. F. KEMP: Bull. Geol. Soc. Am., Vol. X, 1899, pp. 361–382; with plates.

Atlantic coast of pre-Cambrian and later age. He finds a striking predominance of biotite granites and gneisses.

Kemp,[1] in connection with a description of the magnetite deposits of the Adirondacks of New York, publishes a geological map of portions of Elizabethtown and Westport townships in Essex county, showing the distribution of the pre-Cambrian magnetite-bearing gabbros, the gneisses, and the limestones. No point in addition to those given in previous reports appears.

Merrill[2] gives a brief summary account of the geological formations of New York, including the pre-Cambrian of the Adirondack area and of the southeastern part of the state. Accompanying the report is a relief map showing the outlines of the geological formations.

Cushing[3] describes an augite-syenite-gneiss near Loon Lake in the Adirondacks. It is nearly related to the anorthosites in age, inasmuch as it is intrusive in the Grenville series, but it is much older than the pre-Potsdam diabases of the region. A study of the relations of the syenites and anorthosites indicates that the syenites are in part a result of differentiation in the anorthosite magma after reaching its place of final cooling, and in part are somewhat later in date.[4]

Smyth[5] summarizes his ideas to date on the geology of the Adirondacks. Gneisses, limestone, and gabbro are the principal rocks. From studies in the western Adirondacks it is certain that some of the gneisses are of igneous origin, being granites syenites, gabbros, etc., which have been modified by metamorphism; while others, with equal certainty, are altered sediments. But by far the larger part of the gneisses have as yet received no careful study. The limestones are certainly sedimentary. Their relations to the gneisses are in doubt, but some parts of the gneisses are certainly younger than the limestones,

[1] The Titaniferous Iron Ores of the Adirondacks, by J. F. KEMP: Nineteenth Ann. Rept. U. S. Geol. Surv., 1897–8, Part 3, 1899, pp. 377–422. With geological map.

[2] A Guide to the Study of the Collections of the New York State Museum, by F. J. H. MERRILL: Bull. N. Y. State Museum, Vol. IV, No. 19, 1898, pp. 109–262; with geological map.

[3] Augite-Syenite-Gneiss near Loon Lake, New York, by H. P. CUSHING: Bull. Geol. Soc. of Am., Vol. X, 1899, pp. 177–192.

[4] The anorthosites are a part of the great gabbro mass which forms the core of the Adirondacks intruding pre-Cambrian sedimentary and igneous gneisses.

[5] Geology of the Adirondack Region, by C. H. SMYTH, JR.: Appalachia, Vol. IX, No. 1, May 1899.

and this may be true of all. The gabbro breaks through both gneisses and limestones. It presents two phases, an anorthosite, and a gabbro containing abundant pyroxene and other ferro-magnesian minerals. In places also in the western Adirondacks the granites and syenites break through the limestone.

Barlow[1] gives a further account of the results of work being carried on by himself and Dr. Adams in the counties of Hastings, Haliburton, and Renfrew, Province of Ontario. Many of the so-called conglomerates of the Hastings and Grenville series are believed to be autoclastic rocks or pseudoconglomerates which have resulted in the main from complex folding and stretching. Therefore such rocks cannot be cited as evidence of the clastic origin of the Hastings and Grenville series, as has been done.

Barlow[2] describes the geology of the Nipissing-Temiscaming map-sheets, comprising portions of the district of Nipissing, Ontario, and the county of Pontiac, Quebec.

Laurentian and Huronian rocks occupy most of the area. These do not include a few small isolated inliers of crystalline limestone and gneissic rocks which resemble the Grenville rocks to the south and southwest. These are so small in quantity that they are not mapped. Their relations to the Huronian are not discussed.

The Laurentian rocks occupy the two thirds of the area of the two sheets. While probably representing in part the first formed crust of the earth, and therefore the basement upon which the Huronian rocks were laid down, the Laurentian has undergone successive fusions and recementations before reaching its present condition. It is now a complex of plutonic rocks which in general show irruptive relations to the overlying Huronian series. However, on Lake Temiscaming the Laurentian is unconformably below, and in direct contact with, an arkose of Huronian age, which has apparently been derived from the disintegration the Laurentian granite.

The Huronian occupies about a third of the combined area of the two sheets. It is separable into three divisions, in ascending order as

[1] On the Origin of some Archean Conglomerates, by A. E. BARLOW: The Ottawa Naturalist, Vol. XII, 1899, pp. 205–217. See Am. Journ. Sci., 4th series, Vol. III, 1897, pp. 173–180.

[2] Geology and Natural Resources of the Area included by the Nipissing-Temiscaming Map-sheets, comprising Portions of the District of Nipissing, Ontario, and of the County of Pontiac, Quebec, by A. E. Barlow: Ann. Report Geol. Surv. of Canada, Vol. X, Pt. 1, 1899, pp. 302. With geological map.

follows: (1) breccia or breccia-conglomerate, (2) graywacke shale or slate, and (3) feldspathic sandstone or quartzite. The maximum thickness of the first division is 600 feet; of the second, 100 feet; and of the third, 1100 feet. Associated with these clastic rocks are various rocks of igneous origin, including deep-seated diabase and gabbro and volcanic ejectamenta.

Comments.—The nature of the relations of the Huronian and Laurentian rocks has so long been a subject of controversy and the ground has been gone over so many times that comment seems unnecessary. But for readers who have not followed the controversy a statement of one of the main points of contention may be of service. The Laurentian rocks of Barlow and other Canadian geologists form the basement upon which the Huronian rocks were deposited, and they also have intrusive relations to the Huronian rocks. This anomaly is explained by the fact that the granites and gneisses really form the basement upon which the Huronian rocks were deposited, but that since this deposition the granites and gneisses have been softened by fusion, perhaps due to the weight of the overlying rocks, and that they now invade the lower portions of the Huronian rocks.

Other geologists, particularly the United States geologists, have maintained that no evidence has been adduced to show that there has been any softening of the basement granites near their contact with the overlying Huronian sediments; that the granites and gneisses included under the Laurentian by the Canadian geologists are of widely different ages; that they comprise both the original basement rocks, in their original form, upon which the Huronian was deposited, and later rocks, intrusive into both the Laurentian and Huronian; and furthermore, that in most regions it will be possible by close areal mapping to distinguish these different granites and gneisses. They would map the basement granites and gneisses as one series, and separate from them all later intrusives.

Although Mr. Barlow has for many years maintained the total absence of the normal erosion unconformity between the Laurentian granite and the Huronian, he now reports the "discovery" of such a contact near Lake Temiscaming. In finding a normal erosion unconformity in this area he is many years behind Pumpelly, Irving, and Van Hise, as indicated in a comment on a previous article of Mr. Barlow.[1] It is thus now agreed that the original basement granites and

[1] JOUR. GEOL., Vol. II, p. 419.

gneisses are present in this area. Mr. Barlow cites no evidence to show that softening of the granites and gneisses has anywhere occurred immediately subjacent to the sediments, resulting in the invasion of the sediments by the granites and gneisses; that any eruptive relations now found are not those of the normal intrusion of granite magmas into both the original basement and the overlying sediments.

Ells[1] gives an historical account of the geological nomenclature of that part of Canada which extends roughly from the Red River of Manitoba eastward over Canada. The present usage with reference to pre-Cambrian rocks may only be mentioned.

In Nova Scotia the term pre-Cambrian has been given to certain old crystalline rocks which were found to underlie the recognized Cambrian of the coast or of the gold-series, and which were found to strongly resemble certain portions of the Laurentian or Huronian of the western provinces.

In New Brunswick there has been little change in the nomenclature proposed by Matthew, Bailey, and Hunt. The lowest division of the crystalline rocks was held to conform most closely in its details to the Laurentian of the Canadian Survey. This series was divided into a lower and an upper division, the former of which was regarded as the equivalent of the Lower or Fundamental Gneiss of the Ottawa district, while the latter was supposed to represent the limestone and gneiss of the Grenville series of Quebec. The Huronian was made to include three divisions, viz., the Colebrook, the Kingston, and the Coastal. Since this time Matthew has introduced the term Etcheminian to designate certain fossiliferous sediments found beneath the middle Cambrian, probably belonging to the more recent portion of the pre-Cambrian formations.

In Ontario and Quebec the oldest granite-gneiss may be styled Laurentian. The second member of the scale, or the Huronian, may be made to include, as its lowest portion, that part of the crystalline series, once regarded also as part of the Laurentian system, and known locally under the names Grenville and Hastings series, the relations of which to the Laurentian proper are apparently of two kinds, either a stratigraphical sequence, with a probable unconformity, owing to their difference in origin; or a contact of intrusion; and that portions of the Grenville and Hastings series correspond, while the latter is carried

[1] Canadian Geological Nomenclature, by R. W. ELLS: Trans. Royal Soc. of Canada, 2d series, Vol. V, sec. IV, 1899, pp. 3–38.

upward through less altered sediments to the upper members of the Huronian system.

In the Lake Superior region the Huronian is succeeded upward by the rocks of the Cambrian, represented by the Upper Copper-bearing series, or the Animikie and Nipigon groups; while in eastern Ontario this portion of the scale is apparently entirely lacking, the formation succeeding the crystalline series being the Potsdam sandstone, which is now held to represent the lowest number of the Cambro-Silurian or Ordovician system.

Comment.—Adequate discussion of the above scheme of nomenclature is quite impossible in the space available. It may be said only that the scheme will be dissented from on many important points by many of the United States geologists.

Crosby[1] describes the Archean-Cambrian contact near Manitou, Col. A sandstone of Cambrian age rests upon an Archean granite complex. The granite floor has very small erosion inequalities. These inequalities are hummocks, not hollows; erosion remnants, and not channels; clearly marking the end, and not the beginning of a process of base-leveling.

It is believed that such an even contact plane between the Cambrian and pre-Cambrian series is widespread and characteristic in North America. It appears to be the case in the valley of the Eagle River and in the canyon of the Grand River above Glenwood, Col.; in the Black Hills of South Dakota, examined by the writer; in the Grand Canyon of the Colorado, described by Walcott; and in Wisconsin, described by Irving.

In the Manitou, Eagle River, and Black Hills areas, throughout the Rocky Mountains, and eastward to Champlain Valley and beyond, the Cambrian has a non-arkose character; it has been thoroughly sorted and washed by water, a fact which indicates that the incursion of the sea was an extremely slow one. It is believed that the plane surface of the Archean has resulted from the incursion of the sea due to the subsidence of the land, and not from the action of subaerial agents, for in the latter case only an approximate plane could have resulted because of differential erosion.

Emmons[2] describes the Archean rocks of the Ten-mile quadrangle of Colorado. These rocks outcrop to the east of the great fault — the

[1] Archean-Cambrian Contact near Manitou, Col., by W. O. Crosby: Bull. Geol. Soc. Am., Vol. X, 1899, pp. 141–164.

[2] Ten-mile District Special Folio, Colorado, by S. F. Emmons: Geol. Atlas of the U. S., No. 48, 1898.

Mosquito fault—running north of Leadville. They consist of granites, granite-gneisses, mica-schists, and amphibolites, with pegmatite veins traversing them in every direction. Gneisses and schists are the prevailing types.

A small patch of Cambrian sediment is found resting unconformably on the Archean to the east of the Mosquito fault.

Hague[1] describes the Archean rocks of the area covered by the Absaroka folio in the northwestern part of the state of Wyoming. These consist of crystalline-schists and gneisses, mainly mica-gneiss, amphibolites, and schists distinctly light colored, which are found only in the northeastern part of the Crandall quadrangle.

Sedimentary rocks of middle Cambrian age overlie the Archean rocks unconformably.

Irving[2] gives a detailed description of the geology of an area in the northern Black Hills of South Dakota. The Algonkian rocks consist of quartzites, slates, phyllites, and schists, all of sedimentary origin. No new point is added concerning the stratigraphy of the pre-Cambrian rocks.

C. K. LEITH.

[1] Absaroka Folio, Wyoming, by ARNOLD HAGUE: Geol. Atlas of the U. S., No. 52, 1899.

[2] A Contribution to the Geology of the Northern Black Hills, by JOHN DUER IRVING: Annals N. Y. Acad. Sci., Vol. XII, 1899, Pt. 9, pp. 187–340.

Studies for Students

THE EOCENE OF NORTH AMERICA WEST OF THE 100TH MERIDIAN (GREENWICH).[1]

CONTENTS.

[1] The following essay is the outcome of a topical study undertaken by the writer as a student at the University of Chicago. While it is based entirely on the literature of the subject, it brings together so many scattered data concerning a series of formations which often seem intangible to the student, that it is printed in the belief that the summation may be serviceable to students who wish to get information beyond that of text-books, and who have not access to the original reports.—[Ed.]

THE Eocene deposits of western North America may be divided into three groups, namely, those laid down in fresh water, those laid down in brackish water, and those laid down in sea water. To these should probably be added those deposited by streams, though this class of formation has not been generally differentiated from the first.

1. *The fresh-water deposits* stretch with many interruptions from New Mexico and Colorado northward and nothwestward through Utah, Wyoming, Montana, North Dakota, the Dominion of Canada, to the Arctic Circle and probably the Arctic Ocean. The formations belonging to this area are the Fort Union, which is the Upper Laramie of the Canadian Geological Survey, the Kenai, Puerco, Torrejon, Wasatch, Bridger, including Green River, Uinta, Huerfano, Mojave, Amyzon, and Manti. In addition there are non-fossiliferous conglomerates which are supposed to be of Eocene age, as follows: Sphinx conglomerate, Pinyon conglomerate, and San Miguel conglomerate.

2. *The brackish-water deposits* extend with interruptions from Oregon through Washington into British Columbia. The formations belonging to this group are Arago and Puget.

3. *The marine deposits* in Oregon and California. The formations belonging to this group are Tyee, Umpqua, Martinez, and Tejon.

In the following pages the known data concerning the distribution and nature of these several formations is summarized, and their correlation as determined by various investigators indicated.

THE FRESH-WATER BEDS.

THE FORT UNION FORMATION.

The Fort Union beds are named from a former military fort on the Missouri River in North Dakota where they are typically exposed. They occur in North Dakota, Montana, extending thence north and northwest into Canada and with interruptions to the Arctic Circle and probably to the Arctic Sea. These beds are thus described by Meek and Hayden[1]: "Beds of clay

[1] Quoted by Clark, U. S. Geol. Surv., Bull. 83, p. 113, 1891.

and sand with round ferruginous concretions and numerous beds, seams, and local deposits of lignite; great numbers of dicotyledonous leaves, stems, etc." Under the name *Paskapoo*, Tyrrell describes this formation as being at least 5700 feet in thickness[1]: "The beds consist of more or less hard, light gray or yellowish-brownish weathering sandstone, usually thick-bedded, but often showing false bedding; also of light bluish-gray and olive sandy shales, often interstratified with bands of hard lamellar ferruginous sandstone, and sometimes with bands of concretionary blue limestone, which burns into an excellent lime. The sandstones consist of very irregular, though slightly rounded, grains of quartz, felspar, and mica, cemented together in a calcareo-argillaceous matrix."[2] Its fauna shows that this entire series is of fresh-water origin.

Because of the nature of the stratigraphy of the rocks of this region, and because of the fact that dinosaurs became extinct immediately before the Paskapoo epoch, because a time of great disturbance "in which the Rocky Mountains were uplifted" preceded the Paskapoo, Tyrrell thinks this break between the Cretaceous and Paskapoo marks the close of the Cretaceous, "and that the Tertiary epoch began with the commencement of the Paskapoo period, during which a great thickness of sandstones and sandy shales was laid down without any apparent break or unconformity. In this Paskapoo series, then, we have the representative of the Eocene of Europe."[3]

Weed, writing of the Crazy Mountains of Montana, says[4]: "These mountains are formed of Livingston beds, conformably overlain by a series of sandstones and clay shales, characterized by fresh-water fauna, and lithologically distinct and readily differentiated from the somber-colored sandstones of volcanic material composing the Livingston beds. The plant remains of these [upper] beds are not of Laramie nor of Denver bed types, but are species characteristic of the strata in the vicinity of Fort

[1] Geol. and Nat. Hist. Surv. of Canada, Ann. Rep. n. s., Vol. II, p. 135 E. 1886.

[2] TYRRELL: loc. cit., p. 136.

[3] Loc. cit., p. 138.

[4] Amer. Geol., Vol. XVIII, pp. 204, 205, 1896.

Union, and that name is therefore adopted for the formation." A section is given showing Fort Union beds to be 4648 feet thick at this place. "The importance of this section, which is the only one known to the writer in which the Fox Hills, Laramie, Livingston, and Fort Union formations occur superimposed, is apparent when it is considered that in eastern Montana and Canada the Fort Union rests directly upon Laramie beds in apparently perfect conformity."[1] Vertebrate fossils were not found, but the invertebrate fossils from the Fort Union beds at this place were submitted to Stanton, who reported that "almost all the species of the list were originally obtained near Fort Union on the Missouri River."[2]

Of Fort Union fossils in the United States National Museum, Weed says[3]: "They have been studied by Professor Knowlton, who reports that the Fort Union flora embraces 169 species. Of this number 130 species are confined to this formation. Of the 39 species found in other terranes, 21 occur in the Miocene, 14 in the Denver (post-Laramie), and 9 in the Laramie. These figures tell their own story." Knowlton states that the flora as a whole is clearly Eocene. This confirms the statement of Newberry that the floras of the Laramie and the Fort Union are totally distinct, "and that these formations should be referred to different geological horizons, the Fort Union to the Tertiary, and the Laramie to the Cretaceous." Weed gives the following table showing "the comparative sections found along the Rocky Mountain front."[4]

Age	Montana	Canada	Colorado
Eocene	Fort Union	Paskapoo 5700′ { Porcupine Hills, Willow Creek	
Post Laramie	Livingston	(Erosion interval)	*b.* Denver beds *a.* Arapahoe beds
	Unconformity		Unconformity
Cretaceous	Laramie	Edmonton (Tyrrell) or Wapiti River (Dawson)	Laramie

[1] WEED: loc. cit., p. 206.

[2] Quoted by Weed, loc. cit., pp. 206, 207.

[3] WEED: loc. cit., p. 210.

[4] Loc. cit., p. 211.

This conclusion concerning the age of the Fort Union formation has been supported by the Dawsons, as shown by the following: "Dr. G. [M.] Dawson and the writer [Sir William Dawson] have, ever since 1875, maintained the lower Eocene age of our [Canadian] Laramie, and of the Fort Union group of the northwestern United States. . . . ."[1]

THE PUERCO FORMATION.

The Puerco formation is located in northwestern New Mexico at the headwaters of Puerco River, from which the formation takes its name, and where it "reaches a thickness of outcrop of about 850 feet."[2] The rocks of this formation consist of "sandstones and gray and green marls."[3] The formation is thus characterized by Wortman:[4] "The thickness of the beds is roughly estimated at 800 to 1000 feet, and as far as can be observed they lie conformably upon the Laramie."

The fossils occur at two horizons which are separated by barren strata 700 to 800 feet thick (not 30 feet as erroneously quoted by Dall in the Eighteenth Annual Report U. S. Geol. Surv., Part II, p. 347). "The lower fossil-bearing strata occur in two layers, the lowermost of which lies within 10 or 15 feet of the base of the formation. This is succeeded after an interval of about 30 feet by a second stratum in which fossils are found. . . . . Both of these strata are red clay, and at no place did we find them more than a few feet in thickness."[5]

This horizon "is especially and sharply distinguished by the occurrence of the remains of Polymastodon, which appear to be entirely absent from the upper horizon."[6] The upper horizon is richer in fossils than the lower. "The genera Chirox and Pantolambda appear to belong exclusively to the upper beds."[7]

[1] Quoted by Knowlton, Bull. V, Geol. Soc. Amer., p. 589, 1894.

[2] CLARK: U. S. Geol. Surv., Bull. No. 83, p. 138, 1891.

[3] CLARK: loc. cit., p. 138.

[4] Quoted by Osborn, Bull. Amer. Mus. Nat. Hist., Vol. VII, p. 1, 1895.

[5] WORTMAN: quoted by Osborn, loc. cit., p. 2.

[6] *Ibid.* [7] *Ibid.*

Wortman believes that the upper fossiliferous horizon contains several layers, and that their vertical range is somewhat greater than that of the lower horizon." Matthew states that the "Upper and Lower Puerco beds do not contain a single species in common, and only three or four genera pass through. The two faunas are entirely distinct. Dr. Wortman proposes to call the upper beds the Torrejon formation, retaining the name Puerco for the lower beds."[1] Scott correlates the Puerco with the Cernaysien of Europe.[2]

THE WASATCH FORMATION.

The Wasatch formation occurs in a large area in Utah, Wyoming, and Colorado. It is equivalent to the Vermillion Creek of King; Bitter Creek of Powell; and Coryphodon beds of Marsh. The fossils indicate that the rocks were deposited in fresh water. "From the outcrops thus broadly sketched it is clear that a single lake extended from longitude 106° 30′ to 112°, stretching northward probably over the greater part of the Green River Basin, and southward to an unknown distance."[3]

The Wasatch beds lie upon the Cretaceous with a discrepancy in dip, as shown by King, of 0° to 25° in many places. Clark says:[4] "The Wasatch strata throughout much of their extent are conformable to the Laramie, but in western Wyoming and eastern Utah a marked unconformity is exhibited." King thus describes the Wasatch formation, which he names Vermillion Creek:[5] "It is made up of a heavy gritty series at the base, which in the region of Vermillion Creek and north of Evanston is gray, but as displayed at Echo Canyon and East Canyon Creek is characterized by the presence of enough red sandstones and clays to give it more of a brick or in places a deep pinkish color. The middle members are of finer material and are more intercalated with clays, while the upper part of the series has shown wherever the group comes in contact with the Green

[1] Science, n. s., Vol. VII, p. 852, 1897. [2] Science, n. s., Vol. II, p. 499, 1895.

[3] King: U. S. Explorations of the 40th Parallel, Systematic Geol., Vol. I, p. 374.

[4] Loc. cit., p. 139. [5] Loc. cit., p. 375.

River series, is made up of striped and banded sandstones, varying from gray to yellow, white, and red, with prevailing white and red tints. As regards the relations of this with the underlying group, it should be repeated that the evidence has finally accumulated so that there can be no longer a doubt where to draw the line between the Cretaceous and the Tertiary series. I unhesitatingly say that the bottom of the Vermillion Creek is the base of the Tertiary, and that it rests in essential unconformity (though locally in accidental conformity) upon the Cretaceous."

Scott, in a paper read before the British Association, correlates the Wasatch with the Suessonien of Europe.[1]

THE BRIDGER FORMATIONS (including Green River and Wind River).

The Bridger is divided by Scott[2] into two substages, namely, Wind River substage (=Green River substage), and Bridger substage. The Bridger deposits are less extensive than the Wasatch.[3] The Wind River beds lie chiefly in the valley of Wind River, Wyoming, east of the Wind River Mountains. The width of their outcrop is from one to five miles, and its length about 100 miles. The beds reach a thickness of 1000 feet, and are composed of sandstones and shales.

The Green River beds are in the valley of the Green River in Wyoming, Colorado, and Utah, on the west side of Wind River Mountains. Paleontological evidence shows them to be of essentially the same age as the Wind River beds, hence the appropriateness of this name for both series. Outliers of Green River beds occur west to about longitude 116° W. in Nevada, and King interprets this fact as showing that the waters in which they were deposited were probably bounded by the Piñon Mountains.[4] "The Green River series rests for the most part unconformably upon the horizontal as well as the highly inclined Vermillon Creek [Wasatch] beds."[5] These beds are described

[1] Science, n. s., Vol. II, p. 499, 1895.
[2] Introduction to Geology, p. 496, 1897.
[3] SCOTT: loc. cit., p. 499.
[4] Loc. cit., p. 393.
[5] KING: loc. cit., p. 378.

as "calcareous sands and slightly siliceous limestones, which are overlaid by remarkably fissile shales." The limestones are about 800 feet thick; the shales 1200 feet thick. The beds contain fresh-water fossils but "no brackish-water forms whatever."[1]

The formation of the Bridger substage is described by King[2] as follows: "Throughout the middle of the Bridger Basin it rests in positions of complete horizontality, and throughout its whole extent shows no evidence of orographical disturbance, such as could be registered in local changes of angle. The aggregate thickness of the beds of this group is estimated as between 2200 and 2500 feet. The material is almost wholly made up of fine sand and clay, arranged in varying proportions and occasionally slightly changed by calcareous mixtures." Scott correlates the Bridger with the Parisien of Europe.[3]

THE HUERFANO FORMATION

The Huerfano beds in Huerfano county, Colorado, were first described by R. C. Hills in 1888. He estimated the thickness to be 8000 feet and made three divisions of the beds. In 1891 Hills identified the upper beds, which consist of clays, soft shales and sand, as Bridger, and estimated its thickness at 3300 feet. Below this lie the Cuchara beds 300 feet thick, and below the Cuchara are the Poison Canyon beds 3500 feet thick. The lower two divisions he considered Lower Eocene. In 1897 Osborn and Wortman visited the region and arrived at the following conclusions[4]: (1) "That west of Huerfano Canyon the variegated marls, clays, soft shales and sands aggregate only 800 to 1000 feet in thickness and are nearly horizontal in position. They may be positively divided into upper beds equivalent to the Bridger,[5] and lower beds, equivalent to the Wind River or Upper Wasatch.

[1] KING: loc. cit., p. 389. [2] Loc. cit., p. 400.

[3] Science, n. s., Vol. II, p. 499, 1895.

[4] OSBORN: Bull. Amer. Mus. Nat. Hist., Vol. IX, p. 250, 1897.

[5] "Bridger" and "Wind River" appear to be used in the sense of "Bridger substage" and "Wind River substage" respectively as used by Scott. Cf. SCOTT'S Introduction to Geology, p. 496, table.

These constitute the only true Huerfano deposits. (2) That the Cuchara and Poison Canyon beds are unconformable with the Huerfano beds and older than the Eocene, probably marine cretaceous as partly determined by the presence of a species of *Baculites* in the yellow sandstone of the typical Poison Canyon section. (3) That the present canyon of the Huerfano River cuts through the base of the main anticlinal axis of post-Laramie origin, which formed the eastern boundary of the lake. This axis extended to the south so as to include the base of Silver Mountain toward the Cuchara divide; but it lies from three to seven miles west of the anticlinal axis described by Professor Hills. (4) That the Huerfano lake deposition did not extend as far to the east or south as Spanish Peaks, and that the variegated beds observed there are of older origin. This would materially affect the geological age of the prominent neighboring laccoliths."

From the above conclusions it will be observed that the Huerfano beds are much more restricted geographically than was supposed by Hills. They occupy a part of the basin of the upper part of Huerfano River, between the Wet Mountains on the northeast and the Sangre de Cristo and Culebra ranges on the west and south. Osborn thinks the beds were formed by the damming of the Huerfano River by a post-Laramie axis of uplift which was afterward trenched by the river. The lake was thus drained.

It appears from Osborn's conclusions that the two divisions of the Huerfano beds represent the two substages of the Bridger stage of Scott. The name Huerfano should be restricted to one of these divisions. The other division should receive a new name.

THE UINTA FORMATION (=Brown's Park group of Powell).

The Uinta formation was named by King from the Uinta Mountains, on the flanks of which its outcrops occur. The Uinta is described as follows[1]: ". . . . it is possible that this group was deposited continuously, at least in part, with the Bridger

[1] Quoted by Clark, loc. cit., p. 143.

group, but at the places where the junction between the two groups have been seen in this region there is an evident unconformity, both of displacement and of erosion. The group consists of fine and course sandstones, with frequent layers of gravel, and occasionally both cherty and calcareous layers occur. The sandstones are sometimes firm and regularly bedded, and sometimes soft and partaking of the character of bad land material. The color varies from gray to dull reddish-brown, the former prevailing north of the Uinta Mountains, the latter south of them." King says the lower members of the Uinta group are, "chiefly rough, gritty conglomerates, passing up into finer grained sandstones, and at certain points developing creamy, calcareous beds."[1]

The vertebrate fossils show the Uinta to be a fresh water deposit. Scott notes that a considerable break [physical?] occurs between the Bridger and the Uinta, and that earth movements took place at this time. He makes the Uinta equivalent to the Paris gypsum deposits[2]. Peterson finds the following succession of strata in the Uinta basin.[3] (1) Wasatch; (2) conformably upon Wasatch, Green River; (3) conformably upon Green River, a series of hard, brown sandstones, alternating with greenish-gray clays; (4) conformably upon this are layers of coarse, brown sandstone alternating with shales; (5) "*true Uinta* or Brown's Park beds of a fine grained soft material . . . . of brick-red color." These last named beds are about 600 feet thick. Describing the highest three (3, 4, and 5 above) Peterson says:[4] "This uppermost strata [stratum] of the Uinta basin has hitherto been reported as resting unconformably upon the Bridger sediment, but no observable breaks were found to distinguish the true Uinta from underlying Bridger sediment. So the writer found it necessary in collecting fossils to divide the beds overlying the Green River shales into three different levels, which are here arranged alphabetically in ascending position

[1] Loc. cit., p. 405. [2] Science, n. s., Vol. II, p. 499, 1895.

[3] Quoted by Osborn, Bull. Amer. Mus. Nat. Hist., Vol. VII, p. 73, 1895.

[4] Quoted by Osborn, loc. cit., p. 74.

[A being lowest]: Horizon C, true Uinta beds 600 feet thick, sandstones and clays brownish and reddish, ferruginous . . . . "Horizon B, 300 feet thick. Soft coarse sandstones and clays. Horizon A, 800 feet thick. Hard brown sandstones immediately overlying the Green River shales." Commenting upon the above field notes Osborn says[1]: "These excellent observations supply one of the most important links in the American lake faunal chain, namely that between the Washakie[2] and the Uinta. The explorations of the present year, 1895, may modify these results, but it is certain we have now not only established a complete faunal transition from the Bridger and Washakie beds upon the one side, to the true Uinta level or Horizon C upon the other, but have demonstrated a closer connection between the fauna of this basin and that of the lowest White River Miocene."

THE AMYZON FORMATION

Under this name Cope has described beds in Elko county, Nevada; in South Park, Colorado; and in central Oregon. He regards them as belonging to the "later Eocene or early Miocene eras."[3] King described and mapped the same beds of Nevada as of Green River age.[4]

Cope thus describes the beds of Oregon: "The regions of the John Day River and Blue Mountains, furnish sections of the formations of central Oregon. . . . . Below the Loup Fork follows the Truckee [Neocene] group, so rich in extinct mammalia, and below this a formation of shales. These [shales] are composed of fine material and vary in color, from a white to a pale brown and reddish-brown They contain vegetable remains in excellent preservation, and undeterminable fishes. The *Taxodium* nearly resembles that from the shales at Osino, Nevada, and on various grounds I suspect that these beds form a part of

[1] Loc. cit., pp. 74, 75.

[2] Beds belonging to the upper part of the Bridger substage lying east of Green River in southern Wyoming. Cf. Clark, U. S. Geol. Surv., Bull. No. 83, pp. 117, 142.

[3] Amer. Nat., Vol. XIII, p. 332, 1879.

[4] U. S. Geol. Explorations of the 40th Parallel, Vol. I, Systematic Geol., p. 393, 1878.

the "Amyzon Group" (*American Naturalist*, June 1880), with the shales of Osino and of the South Park of Colorado."[1] The Amyzon beds of Nevada appear in the accompanying map. Those of Colorado and of Oregon are not here mapped.

THE MANTI FORMATION

Cope has described this formation as follows:[2] "There is, however, a series of calcareous and silico-calcareous beds in central Utah, in Sevier and San Pete counties, which contain the remains of different species of vertebrates than those which have been derived from either the Green River or Amyzon beds. These are *Crocodilus*, sp., *Clastes cuneatus* Cope, and a fish provisionally referred to *Priscacara* under the name *P. testudinaria* Cope. There is nothing to determine to which of the Eocenes this formation should be referred, but it is tolerably certain that it is to be distinguished from the Amyzon beds. In its petrographic characters it is most like the Green River, as it consists in large part of shales. The laminae are generally thicker than those of Green and Bear rivers. The genera *Crocodilus* and *Clastes* have not been found heretofore in Green River beds, although they are abundant in the formations deposited before and after that period. Until its proper position can be ascertained, I propose to call the formation the Manti beds."

Some years later Cope regarded these beds as of probably Wind River age. He says, "A probable second locality of this [Wind River] formation is known in eastern Utah, in the Wasatch Mountains. This formation is known as the Manti beds."[3]

THE MOJAVE FORMATION

Fairbanks has described[4] a formation in southeastern California which is probably Eocene. "On the northern slope of the El Paso range, between Mojave and Owen's Lake, there is a series of beds of clays, sandstone, volcanic tuffs, and interbedded

[1] Proc. Amer. Philos, Soc., Vol. XIX, p. 61, 1880.

[2] Amer. Nat., Vol. XIV, pp. 303, 304, 1880.

[3] *Ibid.*, Vol. XXI, p. 454, 1887.

[4] Geology of eastern California, Am. Geol., Vol. XVII, p. 63, 1896.

lava flows. These are probably 1000 feet or more in thickness and extend over a considerable area between the El Paso range and the Sierra Nevadas. . . . . They are finely exposed in Red Rock canyon and about Black Mountain. . . . . The beds are tilted northward at an angle of 15–20 degrees. . . . . Impressions of leaves occur in the clay immediately above the seam of coal. These were submitted to Dr. F. H. Knowlton who says: 'I have looked over the three small fragments of fossil plants from the Mojave desert with the following result: Two species are represented, *Spindus affinis* Newb., and *Anemia subcretacea* (Sap.) Ett. and Gard. . . . . The plants indicate a Tertiary age without doubt, and they seem to belong to the Eocene. Both species have quite a wide distribution geographically and are confined, with several unimportant exceptions, to the Eocene.'"[1]

EOCENE OF BATES HOLE, WYOMING

In the valley of Bates Creek, Natron county, Wyo., fossiliferous Eocene beds occur. They have been but recently recognized and no published account of them is known to the writer.

THE KENAI FORMATION

The coal bearing beds typically seen on Kenai peninsula, Cook Inlet, Alaska, "but widely spread in British Columbia and over the coast of Alaska and its adjacent islands" are called by Dall and Harris the Kenai group.[2] Cretaceous Aucella beds lie beneath the Kenai, but whether marine beds of the same age as Kenai intervene is uncertain.[3] "In Alaska, at Cook's Inlet, at Unga Island, at Atka and at Nulato in the Yukon valley we find the leaf beds of the Kenai group immediately and conformably overlain by marine beds containing fossil shells which are common to the Miocene of Astoria, Oregon, and to middle and southern California."[4] Kenai rocks consist of "great thicknesses of somewhat loosely consolidated conglomerates, sandstones, and shales, all generally greenish in character. They contain everywhere

[1] FAIRBANKS: loc. cit., pp. 67, 68.

[2] DALL and HARRIS, Bull. No. 84 U. S. Geol. Surv., pp. 234 et. seq., 1892.

[3] *Ibid.*, loc. cit., p. 251.

[4] *Ibid*, loc. cit., p. 251.

plant remains and frequent seams of lignite, and rest unconformably upon the older formations."[1]

The conclusion concerning the age of the Kenai is based upon its fossil plants and upon its stratigraphic relations. In 1892 Dall, after a summary of the evidence, concludes that the Kenai "is probably of Eocene age. . . . ."[2] In 1896 Dall says, "When we consider that the Oligocene Aturia bed is immediately and conformably overlain at Astoria, Oregon, by shales and sandstones undoubtedly equivalent to the Alaskan marine Miocene, and that the latter, in like manner, immediately and conformably overlies the Kenai group it must be considered that the view that the latter is Oligocene seems highly probable."[3]

In the following year Dall places the Kenai beds in the Eocene, remarking that, "They are with little doubt coeval with the Atane beds of Greenland and other arctic leaf-bearing strata. Their exact horizon is doubtful, but some of the plants appear to be common to the lignitic beds of the Mexican gulf coast, and they are provisionally placed here awaiting more definite information."[4]

BRACKISH WATER DEPOSITS

THE PUGET FORMATION

The Puget formation occurs in Washington in the Puget Sound basin upon the western flank of the Cascade range, extending to Burrard's Inlet, British Columbia. At Comox and elsewhere in Vancouver Island. On the eastern side of the Cascade Mountains beds occur which are lithologically like the Puget formation and probably belong to it.[5] No fossils have been found in these beds east of the mountains. The Puget formation is thus described by Willis and Smith:[6]

[1] SPURR: Eighteenth Ann. Rep. U. S. Geol. Surv. for 1896–7, Part III, Economic Geology, p. 194.

[2] DALL and HARRIS: loc. cit., p. 252.

[3] DALL: Seventeenth Ann. Rep. U. S. Geol. Surv., 1895–6, Part I, pp. 841, 842.

[4] Eighteenth Ann. Rep. U. S. Geol. Surv., 1896–7, Part II, p. 345.

[5] SIR WILLIAM DAWSON: Trans. Roy. Soc. Can., n. s., Vol. I, pp. 137, 138, 1895.

[6] Geol. Atlas of the U. S., Tacoma Folio, Washington, 1899.

The Puget formation consists of interbedded sandstones, shales and coal beds aggregating 10,000 feet or more in thickness. Sandstones prevail. They are of variable composition, texture, and color, and are frequently cross stratified. Their composition ranges from a typical arkose, consisting of slightly washed granitic minerals to siliceous clays. The separate beds vary from a few inches to more than 100 feet in thickness. Conglomerates and concentrated quartz sands have not been observed. The variations in color are not such as to distinguish upper and lower sections of the formation. In general the strata are similar and are similarly interbedded from top to bottom.

The shales of the Puget formation are formed of siliceous clayey muds containing sometimes considerable carbonate of iron, and generally more or less carbonaceous matter, which varies in character from finely divided organic material to large leaves and stems. . . . .

Carefully measured sections show that the Puget formation contains more than 125 beds which would attract the attention of a prospector searching for coal. They range from one to sixty feet in thickness, and the workable coal beds in any one section vary from five to ten in number. The valuable coal is found in the lower 3000 feet of the formation as at Carbonado, Wilkison, Burnett and Green River.

The Puget formation contains an abundant flora. Fossils are found throughout the Puget formation. These are brackish-water forms. No marine forms have been found in the Puget beds. Willis thinks the beds were laid down in an estuary in which the northern Cascade range formed a peninsula, and the Olympic Mountains an island.[1]

In 1895–6 Willis made collections "from definitely determined stratigraphic horizons on Green River, above Burnett, on South Prairie Creek, and on Carbon River near Carbonado. A preliminary examination of the fossil plants enables Knowlton to report that the lower beds of the series are Eocene, whereas the upper beds may be of Miocene age. . . . . The measured sections of the Puget series exhibit a total thickness of 5800 feet on Green River, 5500 feet on South Prairie Creek, and 5480 feet in Carbon River Canyon. None of these measures is complete. . . . . The sections probably overlap. . . . ."[2]

[1] Cf. CLARK: loc. cit., p. 197.

[2] WILLIS: Bull. Geol. Soc. Amer., Vol. IX, pp. 5, 6, 1898.

On the evidence furnished by fossil plants Sir William Dawson correlates the Puget formation with the Fort Union formation as will be seen from the following quotation:[1]

> In summing up the results of this study of fossil plants from the Tertiary of southern British Columbia, it appears from a comparison with the flora of the Upper Cretaceous Nanaimo series, that the Burrard's Inlet species are distinct and of more modern aspect. On the other hand they are also distinct from those of the older Oligocene or older Miocene deposits of the Similkameen district and other parts of the interior of British Columbia. Between these they occupy an intermediate position; in this respect corresponding with the Laramie of the interior plains east of the Rocky Mountains. They also resemble this formation in the general facies of the flora, which is not dissimilar from that of the Upper Laramie or Fort Union group. We may thus refer the plants [from Burrard's Inlet] now in question to the Paleocene or Eocene, and regard them as corresponding with those of the Atanekerdluk beds in Greenland, the lignitic series of the McKenzie River, and the beds [Kenai ?] holding similar plants in Alaska. Thus the opinion expressed in 1890, from the very small collection then available was substantially correct; and I find that the late Dr. Newberry had arrived at a similar conclusion from the study of the plants of the Puget group in Washington territory. This flora thus serves to fill up one of the gaps in our western series of fossil plants, namely, that between the Cretaceous and the Lower Miocene. How completely it may fill this gap we do not know at present. . . . .

THE ARAGO FORMATION

The typical outcrop of this formation is at Cape Arago, Oregon. The beds are chiefly sandstones and shales, and dip toward the northeast at an angle of about 30°. Their thickness is 3000 feet. They contain characteristic Eocene fossils.[2] Diller[3] divides the Arago formation at Coos Bay into the Pulaski formation and the Coaledo formation. The Pulaski is the lower. "The Coaledo formation is characterized not only by the presence of coal, but also by the relatively large proportion of beds containing brackish-water fossils. In the other portion [Pulaski] of the Arago formation of the Coos Bay

[1] SIR WILLIAM DAWSON: Proc. Roy. Soc. Can., n. s., Vol. I, pp. 150, 151, 1895.

[2] DALL: Eighteenth Ann. U. S. Geol. Surv., 1895–6, Part II, p. 343.

[3] Nineteenth Ann. Rep. U. S. Geol. Survey, 1897–8, Part III, p. 320.

quadrangle more than mere traces of coal do not occur, and strata containing brackish-water fossils are rare."[1]

THE MARINE FORMATIONS

THE MARTINEZ FORMATION

The name Martinez was first applied by Gabb[2] to a division of Cretaceous rocks of California. The name comes from the town Martinez, near which typical exposures occur. In recent years the formation has been studied critically by Stanton and by Merriam. "Mr. Stanton has shown the Martinez of Gabb to consist of two parts, one characteristic Cretaceous and inseparable from the Chico group, the other being more closely related faunally and stratigraphically to the Tejon-Eocene than to Chico."[3] The latter was called Lower Tejon by Stanton. Merriam observes that at numerous points on the Pacific coast where the Tejon has been found it always contains an easily recognized fauna. From studies of the faunas in the vicinity of Martinez he proposes (following a suggestion of Stanton) to apply the name Martinez to the Lower Tejon of Stanton.

> In the vicinity of Martinez, the Martinez and Tejon groups form an apparently conformable series between two and three thousand feet in thickness and about equally divided between the two. The faunas, though overlapping, are in the main quite distinct. . . . While some intermingling of species exists, it is not greater than we should expect to find in adjoining groups or periods. . . . The two sets of strata, or two faunas, while belonging perhaps to the two series, represent different periods in the geological history of California, periods quite as distinct so far as faunal evidence is concerned, as the Miocene and Pliocene, or the Pliocene and Quaternary.[4]

The Martinez formation is characterized as "comprising, in the typical locality between one and two thousand feet of sandstones, shales and glauconitic sands," forming "the lower part of a presumably conformable series, the upper portion of which is formed by the Tejon. It contains a known fauna of over sixty

[1] DILLER: loc. cit., p. 320.

[2] Cf. MERRIAM: JOUR. GEOL., Vol. V, p. 767, 1897.

[3] MERRIAM: loc. cit., p. 768.

[4] MERRIAM: loc. cit., p. 774.

species of which the greater portion is peculiar to itself."[1] Its fossils are marine.

THE TEJON FORMATION

This formation was named[2] in 1869 by Whitney, from Fort Tejon, Cal. "The deposits are chiefly conglomerates, sandstones, and shales, in which beds of lignite are not infrequently intercalated, and which less often contain bands of calcareous rock." Clark[3] quotes Whitney (?) as stating that "The conglomerates are very coarse, containing many bowlders from three to six inches in diameter of granite and metamorphic rocks. . . . Portions of the sandstones are very fossiliferous. . . . The strata are very much disturbed, both dip and strike being very variable. . . ." The fossils are marine. Beneath the Tejon is the Chico formation. White, Becker and others state that the Tejon of California lies conformably upon the Chico — the two forming one series.[4] Yet writing of the series at New Idria, Cal., White says, "There is near its middle, a recognizable change of aspect of the strata. . . ."[5] Becker says "The Tejon strata of New Idria are mostly heavy-bedded sandstones of a peculiarly light color, which thus distinguishes them from the tawny Chico standstones."[6]

It is stated also that the Miocene overlies the Tejon conformably. But near Martinez Merriam has shown a pronounced change of fauna, as has been already mentioned. Diller[7] has shown that "All of the facts yet known indicate that in Oregon and northern California there is a faunal and stratigraphic break between the Chico and the Tejon." Perhaps the conformity reported from southern California will be found to be local, or only apparent. Certainly the structural and faunal relations already discussed separate the Tejon from the Chico and from the Martinez. The Tejon is a distinct formation. Near Merced falls, near the boundary of Merced and Mariposa counties,

[1] MERRIAM: loc. cit., p. 775.

[2] Cf. CLARK: loc. cit., p. 100.

[3] CLARK: loc. cit., p. 101.

[4] Cf. CLARK: loc. cit., p. 102.

[5] Quoted by Clark, loc. cit., p. 102.

[6] *Ibid.*

[7] Bull. Geol. Soc. Amer., Vol. IV, p. 220

California, Turner and Ransome describe[1] small patches of Tejon sandstones capping the hills. "This rests almost horizontally upon the nearly vertical edges of the Mariposa [Jura-Trias] slates. . . . The sandstones are overlain to the west by the light colored sandstones of the Ione formation. The two series are probably not absolutely conformable, as the Ione transgresses onto the rocks of the Bed-rock series farther west." Tejon fossils are found in this formation. The Tejon is found in Oregon in the valley of the Willamette River at Albany and at other localities. Clark states that "The Tejon strata of Oregon have been found in a few widely separated localities in the central and northern portions of the state. The most southern yet observed is Coos Bay."[2] But he cites no literature on the the subject, and Diller, in his discussion of the "Coos Bay Coal Field,"[3] makes no mention of Tejon strata.

The Astoria beds at the mouth of Snake River are regarded as Oligocene.

THE UMPQUA FORMATION.

The Eocene described in the Folio of the Roseburg quadrangle, Oregon, rests directly upon an eroded surface of the Upper Cretaceous (Myrtle) formation.[4] There are evidences of considerable erosion in the region before the deposit of the Eocene beds. This leads Diller to believe that Chico may have been present and eroded away. Diller describes the Eocene sedimentary beds under the names "Umpqua formation," from the Umpqua River on which the outcrops occur: "Wilbur tufflentils;" and "Tyee sandstone." The most extensive and important of these is the Umpqua. It lies unconformably upon Cretaceous rocks, and "stretches far beyond the Roseburg quadrangle and plays an important rôle in the makeup of the whole country west of the Cascade Range." The

[1] Geol. Atlas of U. S., Sonora Folio, Calif., 1897.

[2] U. S. Geol. Surv., Bull. 83, p. 103.

[3] Nineteenth Ann. Rep. U. S. Geol. Surv. for 1897–8, Part III, Economic Geology, p. 309 et seq.

[4] DILLER: Geol. Atlas U. S., Roseburg Folio, Ore., 1898.

"formation is composed of an extensive series of conglomerates, sandstones and shales, with terraces here and there of calcareous siliceous beds, which, although of small extent, on account of their exceptional character are treated separately as the Wilbur formation."[1] The Umpqua formation has a maximum exposure of about twelve thousand feet The beds thicken toward the northwest. The bowlders of the Umpqua formation become larger toward the east and south, showing that the land from which they were derived lay in this direction. In places the Umpqua contains abundant marine fossils, *Cardita planicosta* and *Turritella uvasaria* being typical Eocene forms. Thin, small beds of coal also occur.

THE TYEE SANDSTONE

The Tyee sandstone occupies a small area in the vicinity of Roseburg, Ore. "It immediately overlies the Umpqua formation, from whose sandstones it differs chiefly in being heavier bedded and containing more conspicuous scales of mica."[2] It reaches a thickness of about 1000 feet. In places it contains characteristic marine Eocene fossils. The position of the Umpqua and Tyee beds in the geological column cannot be given with certainty. They overlie the Myrtle beds which, according to Stanton, belong to "the lower half of the Upper Cretaceous."[3] Upon the Umpqua, in apparent conformity, lies the "Oakland limestone-lentils" of "probably Oligocene, most likely Upper Oligocene" age.[4] From these relations, from their geographical position and from their fossils I place the Umpqua and Tyee provisionally in the column above the Tejon. If this be their true position they form the latest marine Eocene beds known on the Pacific coast.

THE ATURIA FORMATION

The Aturia beds occur at the water's edge at Astoria, Ore. Formerly they were not distinguished from the overlying shales and sandstones. But in 1880 Condon[5] showed that they are

[1] DILLER: loc. cit. [2] *Ibid.* [3] Quoted by Diller, loc. cit.
[4] DILLER: loc. cit. [5] Amer. Naturalist, Vol. XIV, 1880.

distinct and that the presence of *Aturia ziczac* determines these lower beds to be Eocene or Oligocene. The overlying shales and sandstones do not contain this fossil and are regarded as Miocene. In his "Correlation tables of Tertiary formations: data to 1895" Dall places the Aturia beds in Lower Oligocene, Astoria shales in Upper Oligocene, and Astoria sandstones in Miocene.[1]

UNFOSSILIFEROUS FORMATIONS

THE SPHINX CONGLOMERATE FORMATION

Sphinx conglomerate is the name applied by Peale[2] to a group of nonfossiliferous beds covering an area of about two square miles, but having a thickness of 2000 to 3000 feet. The formation occurs in the Madison Mountain range, Montana. The beds consist of "reddish sandstones and coarse conglomerates of limestone pebbles and bowlders cemented with a reddish sand." They are horizontal and stratified. They are described and mapped as Eocene.

THE PIÑON CONGLOMERATE FORMATION

Weed describes[3] briefly, under the name Piñon conglomerate, certain beds which occur in the southern part of the Yellowstone National Park. He says they consist of a series of conglomerate beds with local intercalations of sandstone, the formation resting unconformably upon the upturned Laramie (Cretaceous)." No fossils are mentioned and they are presumably nonfossiliferous. They are described and mapped as Eocene.

THE SAN MIGUEL FORMATION

The San Miguel formation was named by Purington[4] and referred by him to the Eocene "because of the great unconformity at its base and because it underlies the volcanic complex, which is thought to be of Eocene age in the portions here developed." It occurs near Telluride and Silverton, Col., and rests

[1] Eighteenth Ann. Rep. U. S. Geol. Surv., 1895–6, Part II, pp. 327–348.

[2] Geol. Atlas of U. S., Three Forks Folio, Mont., 1896.

[3] Geol. Atlas of U. S., Yellowstone National Park Folio, 1896.

[4] Geol. Atlas of U. S., Telluride Folio, Col., 1899.

unconformably upon Mesozoic and Paleozoic strata. No fossils have been reported from it. It consists of a coarse, variable conglomerate. Its thickness varies from a few feet to 1000 feet. It is thicker toward the west and dips toward the east.

Some geologists, however, would dispute the right of the San Miguel formation to a place among the Eocene formations on the grounds on which Purington places it there. If it is admitted to the Eocene epoch, there would seem to be no good reason for excluding a number of other formations, among which are the Denver and the Arapahoe beds. Geologists appear to be not fully agreed upon the criteria that shall determine the base of the Eocene.

INTERPRETATION

Having reviewed the various Eocene formations of the region, we may now consider some of the conditions presented by the region as a whole, and some of the problems involved in its history.

Physiography and Climate.— On the Pacific coast the Tejon as now known was deposited in marine water which occupied the great valley of California and western Oregon. It is not known whether the beds of Oregon and California were connected with each other or not. This interior sea in which the Tejon of California was deposited probably connected with the ocean in southern California. There may have been several connecting channels. No definite knowledge exists upon the subject. Before the end of the Tejon deposition the Chico area in Oregon, which had been land and subject to erosion, went down beneath the sea, and beds of Upper Tejon age, possibly underlain by Martinez, were deposited upon it. Probably the same subsidence admitted the sea in which the Umpqua and Tyee beds were deposited a little farther to the southwest. If so, these beds are to be correlated with the Tejon. The correlation of these geographically separated beds must finally be decided by their fossils.

The plants of the Kenai formation indicate a temperate climate at the time of their growth. This climate probably

prevailed over North America, Greenland and Europe, reaching to Spitzbergen. Dall says[1] it may be considered as reasonably certain "that the period during which in the arctic regions the last temperate flora flourished was in a general way the same for all parts of the arctic. It would seem highly improbable that a temperate climate should exist in Spitzbergen and not at the same time in Greenland and Alaska, or *vice versa*." Moreover the nature of the plants of the regions named forms the basis of this statement. The Kenai beds are regarded as fresh water deposits and represent a low land area, which was subsequently still further depressed allowing the Miocene sea to cover it. Dawson[2] says:

It would be rash to decide on the climatal conditions on the west coast of America in the Eocene period, from the plants yet known. But so far as they can give information we may infer that the Cretaceous climate was somewhat warmer than that of the Eocene, but that both attained a higher temperature than that of the present day in the same latitudes, while in the Miocene age the climatal conditions were not very different from those now prevailing in the region.

The Fort Union beds are perhaps the oldest that have been certainly determined to be Eocene. They occupy the plains region of the north. Their limit to the south is unknown, but Haworth[3] believes that near the beginning of Eocene time Tertiary deposits spread continuously from the Dakota-Nebraska area over western Kansas, Indian Territory, and Texas.

Immediately succeeding or perhaps in part contemporaneous with the Fort Union deposits a series of so-called lake deposits was formed on the plains of the summit region bordering the Rocky Mountains on the east. Elevation or warping of the continent and especially of the mountains of this region appears to have checked the drainage in certain directions, so as to form lakes. The oldest and lowest of these deposits are toward the south and west (Puerco); the newest and highest toward the north and east. Probably during Eocene time the uplift in this

[1] Seventeenth Ann. Rep. U. S. Geol. Surv. 1895–6, Part I, p. 839.

[2] Proc. Roy. Soc. Can., n. s., Vol. I, p. 151, 1895.

[3] The Univ. Geol. Surv. of Kans., Vol. II, p. 253, 1896.

region was greater in the southwestern part than in the northeastern part.

THE ORIGIN OF THE SO-CALLED LAKE DEPOSITS

The stratified deposits of the Wasatch, Bridger, Uinta, and others of like nature have been regarded and referred to as lake deposits. Dutton seems to have been the first to recognize and to point out the fact that some of them are not of lacustrine origin. As early as 1880, in his report on the High Plateaus of Utah he says:[1]

> There is another class of conglomerates which claims our special attention. These are of alluvial origin, formed, not beneath the surface of the sea nor of lakes, but on the land itself. They do not seem to have received from investigators all the attention and study which they merit. . . . . Throughout great portions of the Rocky Mountain region they are accumulating today upon a grand scale and have accumulated very extensively in the past.

He then describes the formation and coalescence of alluvial cones containing well-stratified material. Yet this idea of subaërial deposition seems not to have been further emphasized either by Dutton or by others. For a little later he writes[2] "The whole region [High Plateau], with the exception of the mountain platforms and preëxisting mainlands, has passed through this lucastrine stage."

In 1896 Gilbert[3] clearly interpreted certain stratified deposits of Colorado as fluviatile. He speaks thus of the Upland sands and gravels of the Arkansas River basin :

> Whatever the cause the streams which flowed from the mountains onto the plains, and thence eastward across the plains, ceased to carve valleys in the region of the plains, and began to deposit sediment. When they had filled their channels so that their beds lay higher than the neighboring country, they broke through their banks, shifting their courses to new positions and they then came to flow in succession over all parts of the plains, and to distribute their deposits widely, so that the whole plain of the district here described was covered by sands and gravels brought from the canyons and valleys of the Rocky Mountains.

[1] Geol. of the High Plateaus of Utah, pp. 219 et seq., 1880.

[2] The Grand Canyon of the Colorado, p. 216, 1882.

[3] Seventeenth Ann. Rep. U. S. Geol. Surv. for 1895–6, Part II, pp. 575, 576.

In studying the Tertiary deposits of Kansas Haworth reaches similar conclusions. He says:[1]

> The relative positions of gravel, sand and clay of the Tertiary over the whole of Kansas . . . . correspond much better to river deposits than to lake deposits. . . . It is quite possible that during Tertiary time . . . . lesser local lakes and lagoons and swamps and marshes may have existed in different places and for varying lengths of time. But when we consider the Kansas Tertiary as a whole and yet in detail, it must be admitted that the materials themselves have many indications of river deposits and a very few of lake deposits.

Matthew,[2] in discussing the question whether the White River Tertiary is an eolian formation, considers the objections to the lacustrine hypothesis and gives reasons for his believing it to be of eolian origin. He reaches the conclusion that the "White River clays in Colorado, at least, are chiefly eolian deposits. . . . . Most of the sandstones are probably fluviatile. . . . . Some sandstones may be eolian" (407). This position, however, cannot at present be regarded as established; but the question of lacustrine origin is shown to be an open one.

In 1897 Davis,[3] in discussing the origin of the Denver formation, gives criteria for distinguishing lacustrine from fluviatile deposits. In a later publication[4] the same author compares lacustrine with fluviatile deposits as follows: "In both cases the deposits are stratified; in both cases the deposits may include fine as well as coarse materials; in both cases the area of distribution may be large as well as small; in both cases the thickness of deposits may be great as well as light; in both cases the strata may bear ripple-marks, mud-cracks, cross-bedding, and other indications of small and variable water-depth. With all these similarities, it would not be remarkable if a lake deposit were sometimes called a river deposit, or if a river deposit were

[1] The Univ. Geol. Surv. of Kans., Vol. II, p. 283, 1897.

[2] Amer. Naturalist, Vol. XXXIII, pp. 403–408, 1899.

[3] Science, U. S., Vol. VI, pp. 619–621, 1897.

[4] Freshwater Tertiary Formations of the Rocky Mountain Region. Proc. Amer. Acad. Arts and Sci., Vol. XXXV, pp. 345–373, 1900.

mistaken for a lake deposit; for the safe discrimination of the two classes of deposits must depend on their differences, not on their resemblances. While the marginal sediments of a lake may be coarse, the body of the central sediments must be fine and uniform. The marginal parts of a fluviatile deposit may also be coarser than the forward parts, but the latter may be characterized by frequent variations of texture and structure, and occasionally by filled channels and lateral unconformities" (p. 371).

Some quotations may be given to show that many descriptions of the so-called lake beds would apply equally well to river deposits. Lake terraces are "well marked between Ralston and South Boulder creeks (Colorado), where there is a *blending of lake and river terraces.*[1] Here five distinct terraces are traceable, the lake terraces extending from 100 yards to three miles eastward from the foothills, while those more distinctly of stream origin are from 200 to 700 feet in width."[2] Here the lake and river terraces are not clearly distinguished: the width of the terrace seems to be the principal criterion, and the limits assigned to lake and to river terraces overlap. According to the figures given, the river terraces here reach a width of 700 feet, while some of the lake terraces are only 300 feet wide. Again, from the same monograph, with reference to the present inclination of both Tertiary and Pleistocene deposits, it is said that there is an inclination "in round numbers of ten feet to the mile from the foothill region to the valleys of the Missouri and Mississippi;" this would not admit of the holding of lake waters."[3]

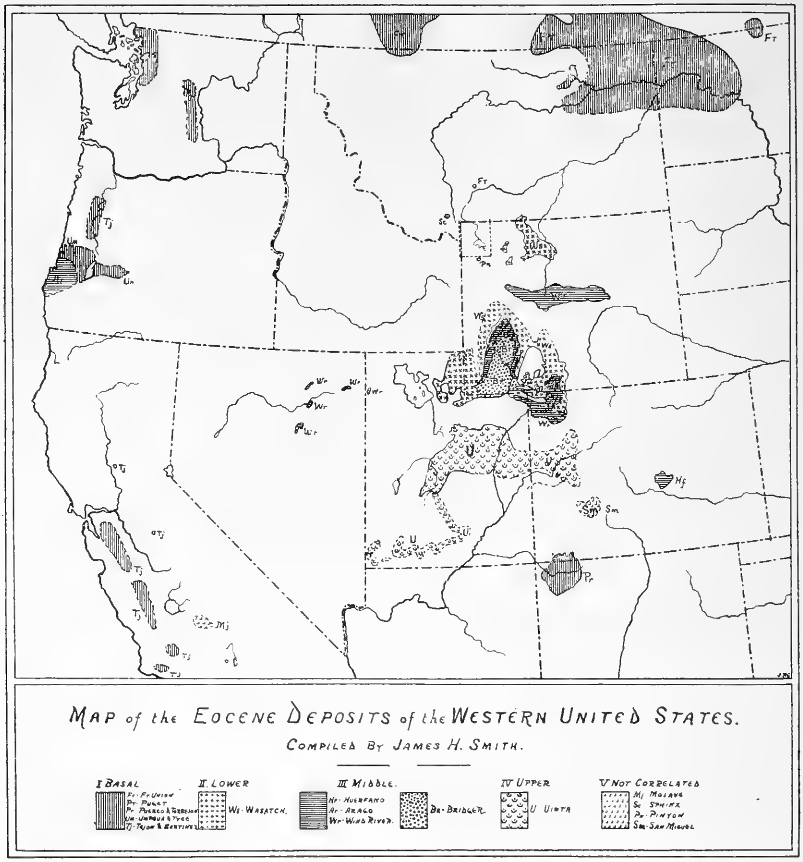
King's Report of the Survey of the 40th Parallel abounds in descriptions of so-called lake beds like the following: "Rough, gritty conglomerates, passing up into finer-grained sandstones, and at certain points developing creamy, calcareous beds" (p. 405). The most characteristic exhibition is in the basin of Vermillion Creek, where a fuller section is displayed. It is made up

[1]The italics are mine.

[2]EMMONS: Geol. of Denver Basin, Monograph XXVII. U. S. Geol. Surv., p. 9, 1896.

[3]*Ibid.*, p. 40.

of a heavy, gritty series at the base. . . . . The middle members are of finer material and are more intercalated with clays, ... while the upper part of the series . . . . is made up of striped and banded sandstones varying from gray to yellow, white and red, with prevailing red and white tints" (p. 375).



MAP of the EOCENE DEPOSITS of the WESTERN UNITED STATES.
COMPILED BY JAMES H. SMITH.

Enough has been said, perhaps, to show that no single explanation will account for the deposition of all the so-called lake beds. At present it seems probable that the deposits will be found to be in part lacustrine, in part fluviatile, and possibly in part eolian. The origin of these deposits cannot be solved by

theoretical considerations alone. Only extensive, critical study in the field will furnish the data upon which the final conclusions must be based. It will be well if the investigator shall enter the field with a clear knowledge of the facts already known, with the possibilities of the different modes of deposition and with the criteria for distinguishing these modes well in mind; and with a willingness to be led to any conclusion to which the facts may conduct him.

CORRELATION TABLE[1]

Eocene	Pacific Coast	Interior	European
Upper	Foraminiferal Shales (?)	Uinta Bridger (upper part)	Ligurien
Middle	Arago	Bridger { Bridger-Huerfano (upper) Wind River-Huerfano (lower)	Bartonien Lutetien
Lower	Kenai (?)	Wasatch	Suessonien
Basal	Tyee Umpqua } (?) Tejon Martinez Puget	Torrejon Puerco Fort Union	Thanetien Montien

JAMES HERVEY SMITH.

[1] Cf. DALL: Eighteenth Ann. Rep. U. S. Geol. Surv., Part II, table facing p. 334, 1897. SCOTT: Science, n. s., Vol. II, p. 499, 1895. Also Introduction to Geology, p. 496. OSBORN: Science, n. s., Vol. XI, p. 562, 1900.

Many Eocene formations, not yet correlated, are omitted from the table.

EDITORIAL

DURING the spring of 1900 the Director of the United States Geological Survey has planned, with the approval of the Secretary of the Interior, an important reorganization of the Geologic Branch. In order that the significance of this step should be appreciated in all its bearings, it is desirable briefly to review the history of the administrative and scientific control within the survey. In the First Annual Report Mr. King set forth a plan of organization based on grand geographic and geologic provinces. The work being then restricted to the national domain west of the 101st meridian, four divisions were established, that of the Rocky Mountains under Emmons, that of the Colorado under Dutton, that of the Great Basin under Gilbert, and of the Pacific under Hague. Each of these divisions corresponded to a province within which the geological phenomena had a certain unity of history and character, and it was wisely argued that the work in each should be directed by a geologist familiar with the special problems of the area entrusted to him. At the same time the limited appropriations of the survey and the adopted policy of surveying the most important mining districts led to a concentration of effort upon Leadville, Eureka, and the Comstock Lode, so that initially comparatively little progress was made in solving the broad geologic problems presented to each division. The principal contributions which the West yielded to the philosophy of the science were made by the surveys through whose consolidation the Geological Survey was created. With the growth of the survey and the addition to its corps of many of the leading minds in American geology, more numerous geographic divisions were established and their limits became more artificial. Thus in the Sixth Annual Report we find enumerated, in addition to the ones first established, the Division of Glacial Geology (Chamberlin), the Division of Volcanic Geology

(Dutton), the Division of the Crystalline Schists of the Appalachian and Lake Superior Regions (Pumpelly and Irving respectively), the Appalachian Region (Gilbert), and the Yellowstone Park (Hague). As divisions became more numerous and restricted, the administrative machinery became more complex, and the opportunities afforded the geologists in charge to study broad problems became more and more limited. Finally it was found that the administrative relations were not only difficult but expensive, since they involved the maintenance of independent offices and clerks, and in the interests of economy and efficiency the system of geographic divisions was abolished in 1893. In its place was substituted an organization by parties, of which there were at first twenty and subsequently nearly double that number, each acting independently of the other except in so far as they were all brought into coöperation through the Director and the Assistant in Geology. Broad coördination of scientific work was for the time being subordinated to the accumulation of facts, especially in the form of geologic maps, rather than to the consideration of philosophic problems. After six years of this activity in the working out of special problems, the time has come for broader supervision and coördination of work, and to this end the following appointments have been made:

George F. Becker, Geologist in Charge of Physical and Chemical Research.

T. C. Chamberlin, Geologist in Charge of all Pleistocene Geology.

S. F. Emmons, Geologist in Charge of Investigation of Metalliferous Ores.

C. Willard Hayes, Geologist in Charge of Investigation of Non-Metalliferous Economic Deposits.

T. W. Stanton, Paleontologist in Charge of Paleontology.

C. R. Van Hise, Geologist in Charge of Pre-Cambrian and Metamorphic Geology.

Bailey Willis (Assistant in Geology to the Director), Geologist in Charge of Areal Geology.

The field of supervision of each geologist in charge is coextensive with the work of the Geological Survey and relates to all parties engaged in work connected with his special subject. His assistance in field or office work may appropriately be

offered or invited. His opinion is to be considered authoritative in subjects under his supervision, and his approval to any report may be required. This authority, however, is restricted to the scientific aspects of the work. Administrative direction remains as heretofore wholly in the hands of the Director, and the work of the survey will proceed after the manner which has been found successful, of authorization of plans of operations after full consideration and conference upon estimates submitted by geologists in charge of parties.

Under the organization now adopted, each geologist is at liberty to make full use of the facts which he observes within his field of operations, the degree of supervision exerted by the geologist in charge of any particular subject to be duly credited in an appropriate manner. For the geologists in charge the plan affords an opportunity to study a special subject in all its aspects throughout the field of operations of the survey, either directly by personal observation or by conference with associates. This opportunity is unequaled in both multiplicity and magnitude of the phenomena presented to each specialist.

B. W.

Reviews.

Department of Geology and Natural Resources of Indiana, Twenty-fourth Annual Report. By W. S. Blatchley, State Geologist. Indianapolis, Ind., 1899.

The current report is a healthy-looking volume of 1078 pages, devoted mainly to the natural history of the state, exclusive of geology. It is well printed and bound, and but one criticism need be made of its typographical make-up, namely, that the title upon the back is not uniform in style and does not align with the titles of preceding volumes; nor they with each other, for that matter.

W. S. Blatchley (pp. 3–40) gives a brief résumé of the natural resources of the state, embodying the salient points appearing in previous reports of the department, together with such facts and statistics as have been brought in the recent work of the department.

Aug. F. Foerste (pp. 41–80) in an interesting paper discusses the synonomy and correlation of the Middle Devonian of Indiana, Kentucky, and Ohio, as embraced in the Cincinnati Anticlinal Region. The formations involved are the Madison beds (Upper Ordovician), Clinton, and Osgood Shale (Lower Niagara). The Madison beds, unfossiliferous and somewhat arenaceous, have caused much confusion, being variously classed as Clinton, Medina, and Ordovician. The various formations referred to the Medina around the flanks of the Cincinnati Anticline are to be correlated with the Madison beds. The oolitic iron-ore facies of the Clinton does not appear west of the Cincinnati axis, the Clinton being represented by a thin, salmon-colored limestone.

The author's opinions regarding the date of the Cincinnati Uplift may be quoted here in advance of the fuller conclusions promised at an early date. "The considerable variation in thickness of these limestones . . . . suggests that the Clinton lies unconformably upon the Lower Silurian, and that this unconformity could be well established if a careful study of this problem were made. The writer was, however, not able to find anything suggesting that this unconformity was in any way related to the formation of the Cincinnati axis. If the

elevation of the Cincinnati axis began in Middle Silurian this still remains to be proved. There is ample proof of local elevations in various parts of Indiana, Kentucky, and Ohio, but not of any connection between these elevations and the formation of the Cincinnati axis. . . . . The result of all my investigations for the last five years in Ohio, Kentucky, and Indiana have tended to confirm the conclusion that at the close of the Upper Silurian a considerable part of the folding which now constitutes the Cincinnati axis took place; that a period of denudation took place, removing most strata from the axis of this fold, and proportionally smaller amounts from its flanks; and that the Devonian rests unconformably upon the denuded Upper Silurian rocks upon the flanks of the axis, and that it rests upon Lower Silurian upon the middle portions of this axis."

J. A. Price (pp. 81–143, with map) outlines the distribution of the Waldron shale (Upper Niagara) through Decatur, Rush, Shelby, and Bartholomew counties, and gives numerous detailed sections covering the Devonian-Silurian parting. The name Hartsville limestone is proposed for a bed of limestone ranging up to ten feet in thickness, lying between the Waldron shale and the Devonian limestone. It is considered to be Silurian in age and as probably the equivalent of the Louisville limestone of Foerste. An interesting case of postglacial stream diversion is noted in the northwestern part of Decatur county. Flat Rock and Little Flat Rock creeks, flowing in southwesterly directions through old valleys, join near Downeyville and flow west through a narrow valley. From near the junction an old col extends to the present valley of Clifty Creek, near Milford. The glacial and preglacial course of the two branches of Flat Rock was through this old col and down Clifty Creek. Later they were diverted into the present valley of Flat Rock.

E. B. Williamson (pp. 229–333, pls. I–VII) on the Dragonflies of Indiana, gives keys for their identification, directions for collecting and preserving, and descriptions of those species known to occur in the state.

R. E. Call (pp. 335–536, pls. I–LXXVII) contributes a most complete and well-illustrated descriptive catalogue of the mollusca of Indiana, including bibliography, keys, and notes on the habits and distribution of all forms found in the state.

W. S. Blatchley (pp. 537–552) in a brief paper describes the batrachians and reptiles of Vigo county.

Stanley Coulter (pp. 553–1002) gives a comprehensive catalogue of the flowering plants, and ferns and their allies, indigenous to the state. The paper includes a bibliography and a voluminous introduction, with sections on the ecologic distribution of the plants (particularly those of the dunes), re-forestation, poisonous plants, and noxious weeds.

The reports of the state inspectors of mines, gas, and oil are also incorporated into the report. From these we learn that the production of coal for 1899 exceeded by 14 per cent. that of any preceding year, while the petroleum product shows an increase in value of 50 per cent. The average rock pressure in the natural-gas field is 155 pounds, as compared with 173 pounds in 1898, foreshadowing the early exhaustion of this popular fuel.

C. E. S.

The Geography of the Region about Devil's Lake and the Dalles of the Wisconsin, with some notes on its Surface Geology. By Rollin D. Salisbury and Wallace W. Atwood. Bulletin No. 5, and No. 1 of the Educational Series of the Wisconsin Geological and Natural History Survey. Published by the State. Madison, Wis., 1900.

It is seldom that a state report is readable for one who is not a geologist, or of more than local interest; but the bulletin just issued by the Wisconsin Geological and Natural History Survey is an exception. The bulletin is a volume of 151 pages with 39 plates and 47 cuts. It is one of the handsomest volumes ever issued by a state survey. The photograph is the best medium for describing nature clearly and sharply, and it has been used to good advantage throughout the report.

The report is a description of the geography and surface geology about Devil's Lake and the Dalles of the Wisconsin. Perhaps there is no region in the interior where more objects of geological interest are found in an area of a few square miles than in the territory about Devil's Lake. All the various types of topography developed by glacial action are seen in contrast with those of the driftless area, and several problems in structural geology are presented. River phenomena especially those connected with the ice invasion, are numerous. One of the best features of the book is the illustrations. The mechanical work is excellent, and each plate is typical of what it illustrates.

The book is divided into two parts: Part I describes the topography, and Part II gives the history of it development.

The quartzite ridges are the most prominent geographic features. In several places they rise to a height of 800 feet above the Wisconsin River and extend for over twenty miles in a general east-west direction. In no place is the quartzite found in horizontal beds, the dip varying between 15 and 90 degrees. Upon and against the quartzite are horizontal beds of sandstone which have been deformed but little; the sandstone topography, modified by the drift, forms the second great geographic feature of the region. It is found north and south of the quartzite ranges, and between them along the valley of the Baraboo.

The first chapter in Part II gives an outline of the history of the formations which outcrop about Baraboo. It is shown how the quartzite was changed from loose sand to quartzite and how deformation and metamorphism were developed during the uplift. The question as to the amount of erosion before the deposition of Cambrian sediments is discussed, but no definite figures can be given. The same is true as to the thickness of the quartzite. After the quartzite had been eroded for a long interval of time, geographic changes caused the sea to again cover the region and the Paleozoic strata were laid down unconformably on the eroded and folded quartzite.

Some time in the Paleozoic, perhaps at the close of the Niagara, the region was again uncovered by the sea, and the work of erosion was begun anew upon the sediments which now completely covered the quartzite bluffs.

In chapter III is given a concise treatment of rain and river erosion, adapted to the area in hand. The question of base-leveling is also discussed. Chapter IV is given over to the description of striking scenic features about Baraboo such as Devil's Lake, the Narrows, Parfrey's and Dorward's Glens, the Dalles of the Wisconsin, Natural Bridge and Castle Rock.

Chapter V deals with the glacial period and is the longest and most important in the book. The first part of the chapter is devoted to a discussion of ice, ice action, and the general results of an ice invasion. As far as possible the illustrations are taken from the region of Baraboo.

The last part of the chapter deals with the changes in drainage effected by the ice. At the time the ice was on, much of the country to the west was covered by large lakes. As the ice retreated these lakes

were drained, giving rise to many smaller bodies of water. The remnants of some of them are still in existence.

The bulletin will be useful to teachers and to geologists in general. Good use can be made of it as collateral reading in the class room. It is No. I in the Educational Series of the Wisconsin Geological Survey and is intended for use in schools. It is an innovation in state survey work and will be of great help in the teaching of geography and geology.

F. H. H. C.

A Preliminary Report on a Part of the Clays of Georgia. By GEORGE E. LADD, Assistant Geologist. Bulletin No. 6 A, Geological Survey of Georgia, 1898.

Preliminary Report on the Clays of Alabama. By HEINRICH RIES, Ph.D. Geological Survey of Alabama, Bulletin No. 6, 1900.

The volume on the clays of Georgia contains a general discussion of clays, touching their origin, composition, properties, especially those which affect their commercial value, and a discussion of the modes of handling and testing clays. A chapter is devoted to the "Fall Line" clays, on which the field work in preparation for the volume was chiefly concentrated. The results of this field work, stated in the author's language, were: "First, the tracing of the Cretaceous strata eastward, across the state, thus necessitating a modification of the geological map of Georgia, which has hitherto limited the Cretaceous to a strip of territory, traversing the central western part of the state. Second, the discovery of white kaolin, some of which ranks with the valuable South Carolina deposits as 'paper clay.' Third, the experimental proof that some of these kaolins, suitable for fire-clay, are more refractory than any of the noted fire-clays of the United States."

The clays of the state which are found to be commercially valuable are mainly in the Coastal Plain, and a sketch of the geology and physiography of this part of the state is introduced. The clay industries of the state are reviewed by localities, and some comparatives notes gathered from other states are introduced. The excellent paper and typography of the volume are to be noted as adding greatly to the attractiveness and readability of the bulletin.

The bulletin of the survey of Alabama likewise contains a general discussion of clays, touching the same general points as the discussion

opening the preceding volume. A chapter is introduced by Dr. Smith outlining the geological relations of the clays of the state. The subject is, however, incomplete, since the Tertiary and post-Tertiary clays receive little specific consideration, and it is indicated that they have not been studied in detail.

The clays of Alabama are considered with reference to their physical and chemical properties, and are discussed under the following headings: China clays, which occur in six counties; fire clays, which occur in seven counties; pottery or stoneware clays, which occur in ten counties; and brick clays, which are mentioned in eight counties. This latter class of clays must be far from complete, since the Tertiary and Pleistocene clays appropriate for brickmaking must be very widespread.

In both these bulletins the educational intent is evident for, in both cases the authors appear to have had in mind readers who have no special knowledge of geology. The idea that geological reports should be written for those who are not familiar with the technicalities of the science is fortunately one which is gaining ground, as the recent publications of many state state surveys show.

R. D. S.

THE

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THE ORIGIN OF BEACH CUSPS

In the April-May 1900 number of this Journal, p. 237, Mark S. W. Jefferson has an interesting article upon "Beach Cusps.' I have often noticed these peculiar beach forms and was for some time puzzled to know how they were produced. The explanation offered by Mr. Jefferson for those on the Lynn Beach, Massachusetts, is that they "must be ascribed to the agency of the seaweed piled up on the beach, modifying the action of the greater waves." The attention I have been able to give the subject leads me to the conclusion that beach cusps are formed by the interference of two sets of waves of translation upon the beach. I know of no peculiarities of these cusps that are not explained by this theory of their origin. It will be understood by reference to the accompanying diagram, Fig. 1. The concentric lines represent two sets of waves advancing on the beach in the directions indicated by the arrows and crossing each other along the broken lines. In deep water these are waves of oscillation, but when they reach the shallow water on the beach they become waves of translation and interfere with each other where they converge upon the shore. The tendency is for them to check each other along these lines of interference and to heap up the sands at the points marked A, where they strike the beach. At the points marked B the waves diverge

and throw the beach sands and all floating material alternately right and left.

In the diagram the waves are represented as being equal distances apart, the shore has a regular curve and the cusps are

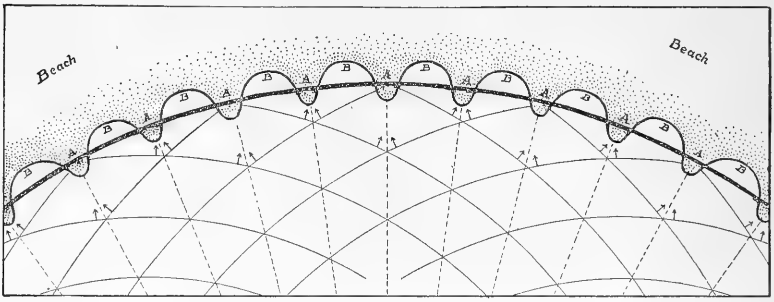


FIG. 1.—Diagram illustrating the formation of beach cusps. The concentric lines represent two sets of wave crests. The heavy line is the curve of a beach which, with these waves, would yield cusps of uniform size.

uniformly spaced. Such regularity is not to be expected in nature. The waves are not so evenly spaced, the depth of the water varies near the shore, and the waves do not all strike the shore at the same angle.

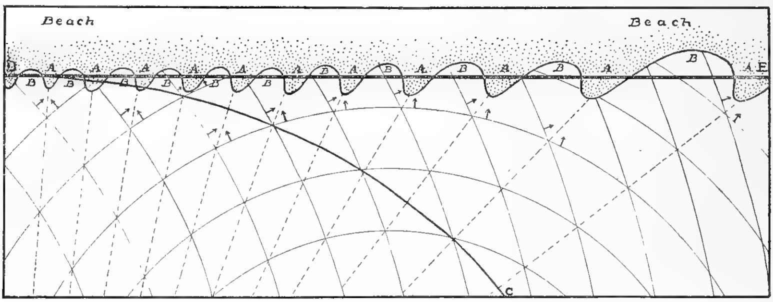


FIG. 2.—Diagram illustrating the formation of cusps of different sizes upon a straight beach D E. If D C were the beach line, these waves would produce cusps of uniform size.

In Fig. 2 the waves are represented as breaking upon a straight beach. If the water off shore were of a uniform depth and the waves were evenly spaced the cusps in this case would, for obvious reasons, be further and further apart from left to

right, as shown along the beach D E. The distance between the cusps is equal to the spaces, measured on the beach, between the radii along which the wave interference approaches the shore.

It is noticeable in California that the cusps are not permanent features of a given beach, but that they are sometimes very pronounced, at others but feebly developed, and at still others altogether obliterated or scarcely perceptible. The accompanying illustration (Fig. 3) is made from a photograph taken by the

FIG. 3.—Cusps on the beach at Santa Cruz, Cal. From a photograph taken from the Sea Beach Hotel, June 14, 1900.

writer June 14, 1900, from the Sea Beach Hotel at Santa Cruz. These particular cusps were 60, 69, 78, and 81 feet apart. They are not always visible on that beach, however. The beach of Half Moon Bay, twenty-five miles south of San Francisco, is sometimes perfectly smooth and sometimes beautifully notched. These variations are due to the changes of the relations of the waves to each other, and of the relations of the radii of the points of interference to the beach (if there are still two sets of waves). It is evident that a variation in the depth of the water off shore would retard or hasten the advance of the waves, and would consequently produce a variation in the direction of these radii and of the distance between the cusps on the beach.

On the northeast coast of Brazil I have observed cusps of remarkable height. These were, however, invariably where the water off shore was deeper and the waves broke with more than usual violence upon the beach.

I am not sure that I know how the two sets of waves referred to in this hypothesis are produced, but I am confident that they do sometimes exist, for I have seen them. It seems possible that they may be formed by an abrupt change of the wind. The concentric form is given them by their entering a bay around a headland. In one case the waves entering a broad-mouthed bay seemed to make two sets on shore by breaking around an island in the middle of the bay's mouth. It is evident that the mathematics of the work of two sets of waves might be considerably enlarged upon, but this is sufficient to call attention to the subject. That seaweeds have nothing to do with the matter is shown by the fact that at several of the places where these phenomena occur there are no seaweeds or other "drift" on the beach.

J. C. BRANNER.

STANFORD UNIVERSITY, CALIFORNIA,
August 10, 1900.

A CONTRIBUTION TO THE NATURAL HISTORY OF MARL.[1]

BOTANISTS have long been familiar with the fact that, in some regions, aquatic plants of all, or nearly all, types are covered with a more or less copious coating of mineral matter, while in other localities the same types of plant life are free from any trace of such covering. In New England, for example, plants growing in the water are generally without such coating, while in Michigan and adjoining states it is generally present. In many lakes and streams the mineral deposit on the stems and leaves of the higher plants is very noticeable, and nearly all vegetation growing in the water is manifestly an agent of precipitation of mineral matter.

Various writers in Europe[2] and America[3] have called attention to the influence of the low types of plants growing in and around hot springs and mineral springs, on the formation of silicious sinter, calcareous tufa, and other characteristic deposits of such springs, and the connection between the beds of calcareous tufa which are sometimes formed about ordinary seepage springs whose waters carry considerable calcareous matter in solution and certain species of moss has been suggested, but so far as the writer knows, no one has given attention to the possible relation of vegetation to the more or less extensive beds of the so-called marl, found about, and in, many of the small lakes in Michigan and the adjacent states. As has been pointed out elsewhere, "Marl" is made up principally of nearly pure calcium carbonate, "carbonate of lime," with greater or less admixture of impurities. When dry and pure, it is white or

[1] Printed by permission of ALFRED C. LANE, State Geologist of Michigan.

[2] COHN: Die Algen des Karlsbader Sprudels, mit Rücksicht auf die Bildung des Sprudel Sinters: Abhandl. der Schles. Gesell., pt. 2, Nat., 1862, p. 35.

[3] WEED: Formation of Travertine and Silicious Sinter by the Vegetation of Hot Springs. U. S. Geol. Surv., IX, Ann. Rept., p. 619, 1889.

slightly cream colored, coarsely granular to finely powdery, very loosely coherent and effervescing freely in acids. On dissolving it particles of vegetable and other organic and insoluble matter are found scattered through the solution.

The ultimate source of this material, except the vegetable matter, is, undoubtedly, the clays of glacial deposits and like disintegrated rock-masses. These clays are rich in finely divided limestone and in the softer rock-forming minerals, some of which contain calcium compounds. Percolating water, containing dissolved carbon dioxide, the so-called carbonic acid gas, readily dissolves the calcium and other metallic salts up to a certain limit. The water with the dissolved matter in it runs along underground until an outlet is reached and issues in the form of a spring. This, in turn, uniting with other springs forms a stream which runs into a lake, carrying along with it the greater part of its mineral load. If the amount of carbon dioxide contained in the water is considerable, some of it will escape on reaching the surface, because of decrease of pressure, and with its escape, if the saturation point for the dissolved mineral matter has been reached, a part of this matter must be dropped in the form of a fine powder, as the water runs along over the surface. Theoretically, then, some, if not a great part of the dissolved matter, should be thrown down along the courses of the streams which connect the original outlets of the water from calcareous clays and lakes where marl occurs, and we should find the marl occurring in small deposits along these streams wherever there is slack water. Moreover, we should expect the waters of these springs and streams to show more or less milkiness on standing exposed to the normal pressure of the atmosphere at usual temperatures. Actually, however, none of these phenomena have been noted, and we infer that there is not a large amount of calcium dioxide, and not an approach to the saturation point for calcium bicarbonate, in the springs and streams feeding marly lakes.

We are then left, among others, the following alternatives, explanatory of marl formation: (1) The marl is not being

formed under existing conditions, but has been formed in some previous time when conditions were not the same as now. (2) The amount of dissolved salts is so small that the saturation point is not approached until after the lakes are reached and the slow evaporation and the reduction of the amount of dissolved carbon dioxide in the water brings about deposition of the mineral salts. (3) Some other cause, or causes, than the simple release from the water of the solvent carbon dioxide must be sought.

The first of these suggestions is met by the fact that marl is found in lakes at and below the present level of the water, and that it extends in most of them to, or even beyond, the very edge of the marshes around the lakes, and over the bottom in shallow parts of living lakes, even coating pebbles and living shells. (2) The water of lakes with swift flowing and extensive outlets, such as most of our marly lakes have, is changed so rapidly that little if any concentration of a given volume of water would occur while it was in the lake, and there is no probability that any of the lakes visited by the writer have ever been without an outlet. Indeed, many of them have outlets which occupy valleys which have been the channels of much larger streams than the present ones. Moreover, definite measurements which, however, are subject to further investigation, have been made, which show that the volume of water flowing out of these lakes is practically the same as that flowing into them, *i. e.*, the loss by evaporation is too small a factor to be taken into account. Farther, recent investigations[1] have shown that calcium, as the bicarbonate, is soluble to the extent of 238 parts in a million, in water containing no carbon dioxide. As most of our natural waters, even from living clays, contain no more than this amount of salt, even when they carry considerable free carbon dioxide, and many analyses show a less amount of it, the fact becomes plain that even if the carbon dioxide were all lost there would be no precipitation from this cause. (3) Considering these objections as valid it seems

[1] TREADWELL and REUTER: Ueber die Loeslichkeit der Bikarbonate des Calciums und Magnesiums. Zeitschrift für Anorganish-Chemie, Vol. 17, 1898, p. 170.

fitting to examine into the possibility of the plant and animal organisms living in the waters of the lakes being the agents which bring about the reduction of the soluble calcium bicarbonate to the insoluble carbonate even in waters low in the amount of dissolved mineral matter, and containing considerable carbon dioxide. That mollusks can do this is shown by the fact, which has frequently come under the writer's notice, that the relatively thick and heavy shells of species living in fresh water are often partly dissolved and deeply etched by the action of carbonic acid after the animals have, by their processes of selection, fixed the calcium carbonate in their tissues, precipitating it from water so strongly acid and so free from the salt that re-solution begins almost immediately. No natural water seems so free from calcium salts that some species of mollusks are not able to find enough of the necessary mineral matter to build their characteristic shells.

While some limited and rather small deposits of marl are possibly built up, or at least largely contributed to, by molluscan and other invertebrate shells, the deposits which are proving commercially valuable in the region under consideration, do not contain recognizable shell fragments in any preponderance, although numerous nearly entire fragile shells may be readily washed or sifted from the marl. The conditions under which marl is found are such that the grinding of shells into impalpable powder, or fine mud, by strong wave action is improbable, if not impossible, for exposed shores and shallow water of considerable extent are necessary to secure such grinding action, and these are not generally found in connection with marl.

We are, then, reduced to the alternative of considering the action of plants as precipitating agents for the calcium salts. It has been shown already that plants generally become incrusted with mineral matter in our marly lakes, and it is easy to demonstrate that the greater part of the material in the incrustation is calcium carbonate. It is also easy for a casual observer to see that the deposit is not a true secretion of the plants, for it is purely external, and is easily rubbed off the outside of the plants

in flakes, while the tissues beneath show no injury from being deprived of it, and again, as has already been pointed out, the same species of plants in some sections of the country do not have any mineral matter upon them. The deposit is formed incidentally by chemical precipitation upon the surface of the plants, probably only upon the green parts, and in performance of normal and usual processes of the plant organism.

All green plants, whether aquatic or terrestrial, take in the gas, carbon dioxide, through their leaves and stems, and build the carbon atoms and part of the oxygen atoms of which the gas is composed into the new compounds of their own tissues, in the process releasing the remainder of the oxygen atoms. Admitting these facts, which are easily demonstrated by any student of plant physiology, we have two possible causes for the formation of the incrustations upon plants.

If the calcium and other salts are in excess in the water, and are held in solution by carbon dioxide, then the more or less complete abstraction of the gas from the water in direct contact with plants, causes precipitation of the salts upon the parts abstracting the gas, namely, stems and leaves. But in water containing amounts of the salts, especially of the calcium bicarbonate, so small that they would not be precipitated if there were no carbon dioxide present in the water at all, the precipitation may be considered a purely chemical problem, a solution of which may be looked for in the action upon the bicarbonates, of the oxygen set free by the plants. Of these calcium bicarbonate is the most abundant, and the reaction upon it may be taken as typical and expressed by the following chemical equation:

$$CaH_2\,(CO_3)_2 + O = H_2O + CaCO_3 + CO_2 + O \quad \left.\begin{array}{l}\text{calcium}\\ \text{bicarbonate}\end{array}\right\} + \text{oxygen} = \text{water} + \left.\begin{array}{l}\text{calcium}\\ \text{carbonate}\end{array}\right\} + \left.\begin{array}{l}\text{carbon}\\ \text{dioxide}\end{array}\right\} + \text{oxygen}\,,$$

in which the calcium bicarbonate is converted into the normal carbonate by the oxygen liberated by the plants, and both carbon dioxide and oxygen set free, the free oxygen possibly acting still farther to precipitate calcium monocarbonate.

It is probable that the plants actually do precipitate calcium carbonate, both by abstracting carbon dioxide from the water and by freeing oxygen, which in turn acts, while in the nascent state, upon the calcium salt and precipitates it, but in water containing relatively small amounts of calcium bicarbonate the latter would seem to be the probable method.

The calcium salt is deposited in minute crystals, and by the aggregation of these crystals the incrustation is formed on the plants. The crystals are distinguishable as such only for a short time on the newer growths of plants, but the incrustations are said to show a recognizable and characteristic crystalline structure when examined in thin section under a compound microscope with polarized light.

Not all aquatic plants in the same lake seem equally active in the precipitation of mineral matter. Not even all species of the same genera, even when growing side by side, will be coated equally, a fact which seems to indicate some selective metabolic processes not understood. Considering the precipitation of calcium carbonate by plants as established, even if the exact physiological and chemical processes by which this precipitation is brought about, are not yet worked out fully, it is still necessary to consider the constancy of the action and the sufficiency of the agency to produce the extensive deposits of marl which are known.

If one confines his studies simply to the seed-producing plants and other large vegetable forms which are conspicuous in lakes during the summer season, while he will find them covered with a thin coating of manifestly calcareous matter, he will at once be convinced that such work as these plants are doing is but a small factor in the total sedimentation of the lake. On the other hand, if a visit be made to a lake in early spring or late fall, all plants of the higher types will not be found, so that it becomes apparent that this agency is merely a seasonable one and works intermittently. Farther study of the plants of the same body of water, however, shows that the algæ, the less conspicuous and entirely submerged plant organism, must be taken

into account before we finally abandon plants as the agents of precipitation. Of these, two groups, differing widely in structure, habits, and method of precipitation, will be found. The first and most conspicuous, and probably the most important as well, is the Characeæ or Stoneworts. These plants are well known to botanists, and may readily be recognized by their jointed stems, which have at each joint a whorl of radiating branches, which are also jointed. In some species the stems and branches are covered with a thick coating of mineral matter, are almost white, and very brittle because of this covering. These plants not only grow near the surface in shallow water, where it is unoccupied by other plants, but in the deeper parts as well of our ponds and lakes, and, as they thrive where light is feeble, they continue to grow throughout the year, although in winter they must grow less rapidly than in summer, because ice and snow on the surface of the lakes make less favorable light conditions.

The sufficiency of these plants alone to fix and deposit calcium carbonate in large quantities is indicated by the following: In November 1899 the writer collected a large mass of plants of Chara sp?, from which five stems with a few branches were taken at random and without any particular care being taken to prevent the brittle branches from breaking off. The stems were each about 60^{cm} long, and after being dried for some days they were roughly ground in a mortar and dried for one half hour at 100° C., dried and weighed until the weight was constant. The weight of the total solid matter obtained in this way from five plants was 3.6504 grams, 0.73 grams per plant. This was treated with cold hydrochloric acid diluted, twenty parts of water to one of acid, filtered, washed, and the residue dried at 100° C., on a weighed filter paper, until weight was constant. The weight of insoluble matter was 0.5986 grams; of the total soluble matter 3.0518 grams, or .6103 grams per plant. In the lake from which the material analyzed was derived from 50 to 80 plants were counted to the square decimeter of surface in the Chara beds.

A partial quantitative analysis of material from the same source, but using stronger acid to affect solution (hydrochloric acid, diluted with four parts of water), gave the following results:

Insoluble residue	11.19 %
Iron and aluminum oxides	0.722
Calcium carbonate	76.00
Magnesium carbonate	2.359
Soluble organic matter obtained by difference	9.279

The composition of the insoluble residue was obtained by heating the residue to redness in a platinum crucible for one half hour, and the 11.19 per cent. of this matter was found to consist of:

Combustible and volatile matter	9.243 %	= 82.6 %
Mineral matter	1.947	= 17.4

The mineral matter was found to be:

Silica	1.787 %	= 92.4 %
Not determined	.160	= 7.6

Microscopic examination showed the silica to be largely composed of whole and broken tests of diatoms, minute plants which secrete silicious shells and attach themselves to the Chara stems and branches.

The mineral matter obtained in this analysis, reduced to parts per hundred, gives the following:

	Per cent.
Calcium carbonate	93.76
Magnesium carbonate	2.93
Silica and undetermined mineral matter	2.40
Iron and aluminum oxides	.89

This, with a small decrease in the mineral matter and a small amount of organic matter added, would be the composition of ordinary marls, and would be a suitable sample to consider in connection with Portland cement manufacture.

The large amount of silica may be explained by the fact that the material analyzed was collected at a season when diatoms are especially abundant.

It may be well to call attention to the fact that in many marls, especially those of large deposits, which the writer has examined

chemically, the silica has been found to be in the form of diatom shells, and hence, because of the small size and great delicacy of these structures, it is available as a source of silica for calcium silicate in cement making. If such deposits as are made up largely of diatom shells were adjacent to marl beds, it is possible they might be considered as clay and be used in cement making.

From the above considerations, it is evident that both because of the quality and quantity of its works, Chara may be considered an important agent in marl production, and it only becomes necessary to account for the chalky structure of the deposits to make the chain of evidence complete. All algæ are plants of very simple structure, without tough or complicated tissues. Chara stems and branches are made up of aggregations of thin-walled cells, and when the plants die the cell walls must rapidly decay and the residue of lime be left. In a laboratory experiment to determine this factor, it was found that a mass of the broken-up plants placed in the bottom of a tall glass vessel filled with water became decomposed very quickly, giving the characteristic odor of decaying vegetable matter, and after a few weeks all organic matter had disappeared, leaving the incrustations in tubular, very brittle, fragments. In studying the structure of marl, the writer has found that near the top of the beds there is usually a "sandy," or even a coarsely granular structure. This is noticeable, at times, at all depths from which the samples are taken, *i. e.*, in some cases it extends through the bed. Close examination of such marl shows that this coarseness is due to the remains of the characteristic Chara incrustations, and that the "sand" and other course material is made up of easily identifiable fragments of the coatings of stems and branches of the plant. The presence of such coarse matter near the top of the beds may be considered due to sorting action of the waves, and such surface currents as may be caused in ponds and small lakes, in shallow water, by wind action. If these agents are effective in producing the coarser parts of the deposits they may be also considered so in connection with the finer parts as well, for the matter

produced by the breaking and grinding up of fragments is held in suspension for a longer or shorter time, carried about by currents, and finally sinks to the bottom in the quieter and deeper parts of the lakes.

Chara may also be looked upon as an important agent in giving the peculiar distribution to marl which has been noticed by every one who has "prospected" beds of material. The fact is frequently noticed that beds of several, and even as much as twenty or more, feet in thickness will "run out" abruptly into beds of "muck," or pure vegetable débris, of equal thickness. This distribution may show that up to a certain time conditions unfavorable to the growth of Chara are favorable to other plants obtained, until a depth of water was reached at which Chara was able to occupy the bed of muck, covering it from the bottom up, and holding the steep slope of the muck in place by mechanically binding it there by its stems and the root-like bodies by which it is connected with the mud. From the time when the Chara began its occupation of the muck the amount of organic matter left would decrease, and the amount of calcareous deposit would increase, until the latter predominated. The disturbing factors of currents and waves can be disregarded, for these abrupt unions of marl and muck are found, so far as the observations of the writer go, in most sheltered places, and not where either currents or waves could ever have operated with any force or effectiveness. Moreover, in a lake where the marl is evidently now actively extending, the slope was observed to be nearly perpendicular, and the steep banks thus formed were thickly covered with growing Chara, to the exclusion of other large forms of plant life, and the lower parts of the growing stems were buried in mud which was mainly pure marl.

In regard to the species of Chara which seems to be the active agent in precipitation in the lakes of central Michigan, it is the form commonly known as *Chara fragilis*, but it is probable that careful study of the species throughout the range of the marl will reveal, not a single form, but a number of allied species, engaged in the same work. It may be well to suggest that

in lakes to which much silt is brought by inflowing streams, or which have exposed shores where the waves are constantly cutting and stirring up rock débris, the more slowly accumulating marls will be either so impure as to be worthless, or so obscured as to escape notice altogether, even where Chara is abundant. It may also be pointed out that shallow water, strong light, and a bottom of either clay, sand, or muck, present conditions favorable for the growth of the higher vascular plants, and that these cause such rapid accumulation of vegetable débris that the calcareous matter may be hidden by it, even when Chara is a well-marked feature of the life of a given lake.

Another plant form, like Chara an alga, but of a much lower type, which is concerned in the formation of marl is one of the filamentous blue-green algæ, determined by Dr. Julia W. Snow, of the University of Michigan, to be a species of Zonotrichia, or some closely related genus.

The work of this species is entirely different in its appearance from that of Chara, and at first glance would not be attributed to plants at all. It seems to have been nearly overlooked in this country at least by botanists and geologists alike, as but a single incidental reference to it has been found in American literature.[1] Curiously enough, however, material very similar, if not identical, to that under consideration has been described from Michigan in an English periodical devoted to Algæ.[2] In this the alga is identified as *Schizothrix fasciculata* Goment. As comparison of material is not possible at the present time, the plant under consideration is here tentatively called Zonotrichia. The plant grows in relatively long filaments, formed by cells growing end to end, and as they grow, the filaments become incased in calcareous sheaths. The feature of the plant which makes it important in this discussion, however, is its habit of growing in masses or colonies. The colony seems to start at some point of attachment, or on some object like a shell, and to grow outward radially in all directions, each filament independent

[1] McMillan: Minn. Plant Life, 1899, p. 41.

[2] G. Murray: Phycological Memoirs No. XIII, 1895, p. 1, Pl. XIX.

of all others and all precipitating calcium carbonate tubules. The tubules are strong enough to serve as points of attachment for other plants, and these add themselves to the little spheroid, and entangle particles of solid matter, which in turn are held by new growths of the lime-precipitating Zonotrichia, and thus a pebble of greater or less size is formed which to the casual observer is in no wise different from an ordinary water-rounded pebble. These algal calcareous pebbles show both radial and concentric structure and might well be taken for concretions formed by rolling some sticky substance over and over in the wet marl on which they occur but for the fact that a considerable number of them show eccentric radial arrangement, and that the shells of accretion are likewise much thicker on one side than on the other, and finally, because the side which rests on the bottom is usually imperfect and much less compact than the others. The pebbles are characteristically ellipsoidal in shape. The radial lines, noticeable in cross sections of the pebbles, are considered by the writer to be formed by the growth of the filaments, while the concentric lines probably represent periods of growth of the plants, either seasonal or annual. Included within the structure are great numbers of plants, besides the calcareous Zonotrichia, among them considerable numbers of diatoms, and it is probable that a large part of the algal flora of a given lake would be represented by individuals found in one of these pebbles. It is probable that to a certain extent they disintegrate after the plants cease to grow, for they are never very hard when wet. It is possible to recognize them, as lumps of coarser matter, even in very old marl, and the writer has identified them in marl from Cedar Lake, Montcalm county, Mich., which was taken from a bed a foot or more above, and several rods away from, the lake at its present level. From the fact that these pebbles have been found in four typical marl lakes in different parts of Michigan (in Zukey Lake, by Dr. A. C. Lane, who was struck with their peculiar character) and have been reported from a number of others by marl hunters, it is probable that they have a wide distribution in the state and are constant if not

important contributors to marl beds. It may be said in passing that the limy incrustations which are found upon twigs, branches, shells, and other objects in lakes and streams, and called generally "calcareous tufas," are of similar origin and are formed by nearly related, if not by the same, plants that form the pebbles.

Studies have been begun by the writer to solve, if possible, some of the questions which have arisen in connection with the statements embodied in this paper, but enough has already been done to show that these forms of fresh-water algæ are important lime-precipitating agents now, and to suggest the possibility that in all likelihood they have been more active in former geological times, and that, as has been suggested again and again by botanists, the formation of certain structureless limestones, and tufa deposits may have been due to their work.

CHARLES A. DAVIS.

ALMA COLLEGE,
September 1, 1900.

A REMARKABLE MARL LAKE[1]

Early in June 1900 the writer visited Littlefield Lake, Isabella county, Michigan, which, from its peculiar form, and the deposits about it, seemed worthy of special description.

The country about the lake is of a well-marked morainal structure, the till, however, being sandy in places, and noticeably gravelly and bowldery throughout, and formerly heavily covered with pine. The lake occupies a deep depression in a trough-like valley, surrounded by moderately high morainal hills, and from its apparent connection with a series of swampy valleys, suggests a glacial drainage valley, but as it was not followed for any distance its origin was not determined.

The lake itself is about one and one half miles long by three fourths of a mile broad in the widest part, which is near the middle of the long axis, and the shape is that of an irregular blunt-ended crescent. It was said to be over eighty feet deep in the deepest part, but no soundings were made by the writer. Its greatest length is from northwest to southeast, with the outlet at the southern end. There are no considerable streams entering it, but at least three small brooks, fed by springs from the surrounding hills, were noted flowing in, and the outlet is of such size that a boat may be easily floated on it at high water, although its level is maintained during the summer by a dam about two miles below the lake. The main inlet was not seen by the writer.

The shore lines are relatively regular, especially on the east and north sides, the convex side of the crescent, with banks twenty or more feet high close to the water on the east, while on the west side are two rather deeply indented bays. At either end are three small ponds, parasite or daughter-lakes, and surrounding the entire shore, except on the eastern side and the

[1]Printed by permission of Alfred C. Lane, State Geologist of Michigan.

northeastern or inlet end, is a cedar swamp which is underlaid by marl. The outlet is through the most southerly of the daughter-lakes, and the entire shore of the lake is formed by beautifully white marl, the exposures varying in width from a few feet to three or four rods in width, so that as one overlooks the lake from one of the surrounding hills it seems to lay in a basin of white marble.

There are three small islands in the lake, two relatively near together at the northern end, and one quite near the shore at the south end. These islands are also of marl, covered partly with a thin layer of vegetable matter and a scanty growth of grass, bushes, and cedar. There is a visible connection, under water, between at least one of the islands and the nearest shore, and it is probable that all of them are thus connected by submerged banks. The marl on the islands is from twenty-five to thirty feet deep, with sand below.

Explorations in the swampy border of the lake show that the shore was formerly more irregular than now, and that the marl extends back from the water in some places for at least one fourth of a mile, gradually becoming more and more shallow until the solid gravel or clay is reached. The marl is frequently thirty feet deep along the shore, and at no place was it found to be less than fifteen feet deep at the present shore line, the shallowest places being along the shore where the high bank comes down near the water. The deepest vegetable deposit, or peat, found in one hundred and fifty borings in all parts of the deposit was three feet. The main deposits of marl are about the southeast end and along the western side of the lake, with a body of considerable size underlying a swampy area at the north end. Of the six daughter-lakes four are very small, an acre or two in extent, and entirely surrounded by deep marl, the connection between three of them and the mother-lake being shallow and narrow, a few inches deep, and a few feet wide, and only existing at high water, while two of the other three are of much larger size, with marl points extending out from either side of the strait, which is still relatively wide and deep.

Of the two bays on the west side of the lake, one is much narrower than the other, and at the mouths of both, marl points are extending towards each other to a noticeable degree.

At all points along the shore the slope of the marl is very abrupt from the shallow water to the bottom, always more than 45°, and frequently nearly 90°, this steepness being noticable in the small as well as in the parent lakes, while on the east side of the island at the south end of the lake, the wall of marl seemed positively to overhang, although this appearance was probably due to refraction.

The texture of the deepest part of this marl deposit is apparently that of soft putty; a sounding rod passed through it with comparative ease, and samples brought up have a yellowish or creamy color, which disappears as they dry, leaving the color almost pure white. At the surface the marl is coarser, slightly yellowish, and more compact. Where it lies above the water line it is distinctly made up of granular and irregular angular fragments, resembling coarse sand, but the fragments are very brittle, soft, and friable, and may be converted into powder by rubbing between the thumb and fingers.

On the parts of the shores where apparently the wave action is chiefly exerted, there are small rounded calcareous pebbles, mixed with molluscan shells, drift material, and considerable quantities of stems, branches, and more or less broken fragments of the alga Chara, all parts of which are heavily incrusted with calcareous matter. This Chara material was often piled up in windrows of considerable extent at the high-water mark.

The marl banks of the lake, from a little below the water's edge down as far as could be seen, were generally thickly covered with growing Chara. At the time of the writer's visit, and wherever a plant of it was examined, it had a heavy coating of limy matter, which was so closely adherent to the plant as to seem a part of it, and because of this covering the plants were inconspicuous and would easily escape notice.

Little if any other vegetation of any character was growing in the lakes at this season; indeed, from the steep slope of the

banks of marl, it would be hardly possible for any considerable amount of vegetation of higher types than algæ to flourish here, because of the lack of light at the depth at which it would have to grow to establish itself.

As Chara of several species is known to occur within our limits at depths as great as thirty feet, and probably grows at even greater depths where the water is clear and the bottom soil is of the right character, *i. e.*, of clay, finely divided alluvial matter, marl, etc., it is apparent that there must be an immense growth of this type of plants in such a lake as the one under discussion. That there is an abundance of Chara in Littlefield Lake is shown by the amount of drift material, composed of the plant, which has accumulated in heaps at the high-water wave marks along the shore at various places.

From even a casual inspection of this drift accumulation, it is evident that it is the source of much of the granular and sand-like marl on the beaches and in the coarse upper layers of the deposit. This wind-and-wave accumulated material was dry and bleached, and was very brittle—so fragile, indeed, that a mere touch was generally sufficient to break it into fragments, and it passed by insensible gradation from the perfect, unbroken, dried plant form at the high-water mark, in which every detail, even the fruit, is preserved, to inpalpable powder at and below the water's edge.

In other words, we have in Chara, a plant of relatively simple organization, able to grow in abundance under most conditions of light and soil which are unfavorable to more highly developed types, a chief agent in gathering and rendering insoluble calcium and other mineral salts brought into the lake from the clays of the moraine around it by the stream, spring, and seepage waters. After precipitation is accomplished and the plant is dislodged or dies it drifts ashore, where, after the decomposition and drying out of the small amount of vegetable matter, the various erosive agents at work along shore break up the incrusting chalky matter, and the finer fragments are carried into deeper water, the coarser are left along the lines of wave action.

The pebbles mentioned above as occurring on parts of the shore are also the result of the development and growth of an alga, Zonotrichia or a nearly related genus, a much lower type than Chara, having a filamentous form. The vegetable origin of these pebbles would not be suspected until one recently taken from the water is broken open, when it is found to show a radiating structure of bluish-green lines, the color indicating the presence of the plants, as it is characteristic of the group to which Zonotrichia belongs.

The relation of the deposits about Littlefield Lake to the direction of the prevailing strong winds of the region is probably significant.

The area of deposition is at the southeast end and along the whole western side of the lake. The winds which would be most effective in the valley of the lake would be those from the north and northwest, which would drive the surface waters down the lake toward the southern end, and, striking the shore on the eastern side, these currents would be turned across the lake to the west, depositing sediment at the turning area and in slack water beyond. The daughter-lakes are not easily accounted for except in a general sense, that they were formerly deep bays, which, by the building out of points of marl on either side of their mouths, were finally enclosed. The tendency, already noted, for existing bays to have points of marl of spitlike form extend from either side of the mouth would seem to indicate this as a probable method of formation. On the island at the south end of the lake there was manifestly a strong current, which was running southeasterly and depositing fine marl on the east side of the island, the wind, at the time the observation was made, blowing gently from a few points north of west.

As has been already noted, the islands consist of marl from twenty-five to thirty feet deep, the bottom on which they are built up being, to judge from soundings made with an iron rod, of rather fine sand. These foundations of sand have deeper water all around them, if soundings said to have been made by local fishermen can be relied upon; so it is possible they

represent shallows in the original lake bottom, upon which, after Chara had established itself, the marl accumulated, both by direct growth of the plants and by sedimentation. It may be worthy of mention that the Chara growing on the steep banks may, in part, account for their steepness by acting as holding agents, binding the particles of sediment in place by stems and the rootlike organs which the plant sends into the mud. It is probable that but a small part of the Chara that grow in the lake ever reaches the shore wave-line, and much must break up by the purely chemical processes resulting from organic decay in relatively deep water.

CHARLES A. DAVIS.

THE ORIGIN OF THE DÉBRIS-COVERED MESAS OF BOULDER, COLORADO

At the base of the mountains south of Boulder, Colorado, is found a series of table lands, or mesas, which rise 300 to 500 feet above the bed of Boulder Creek, and which slope away from the mountains at an angle of about 3½°. Mesas of a similar nature are found at numerous points along the mountain front, some of them much more extensive than the ones of which I write. This article is the result of a study of those included between Boulder Creek and South Boulder Creek. Their location is shown in Fig. 1. A photograph (Fig. 2) shows their general aspect and their relation to the foothills. Fig. 3 is an east-west section of the mesa shown in the photograph, giving its structure. A sheet of unconsolidated fragmental material, 25 to 50 feet in thickness, rests upon the eroded surface of the upturned Cretaceous formations, principally the Fort Pierre shale. The Benton, Niobrara, and Dakota are inconspicuous at this point, owing to the proximity of the Boulder arch described by Eldridge.[1] This covering of débris forms the protecting cap of the mesas. It is composed almost wholly of sandstone and conglomerate from the Red Beds of Permo-Trias age, which formerly covered the mountain front and which still rise about 2000 feet above the level of the plains. Their serrate peaks are shown along the lower mountain front in Fig. 2. At this point the Red Beds dip at an angle of 48°. The fragments of the detrital capping vary in size from grains of sand to bowlders twenty feet in diameter. They are notably angular, bearing little evidence of long continued water action, and are very imperfectly sorted. Coarse and fine materials are bedded together in the most intimate relations. Originally they formed a continuous sheet of débris, the greater part of which has been destroyed by subsequent erosion.

[1] U. S. Geol. Surv., Mon. 27, p. 105.

The mesas are bordered by rather sharp declivities. Between the foot of these declivities and the flood plains of the creeks is an inclined surface which may be called the mesa-terrace. It is a wide shelf-like surface extending from the base of the mesas

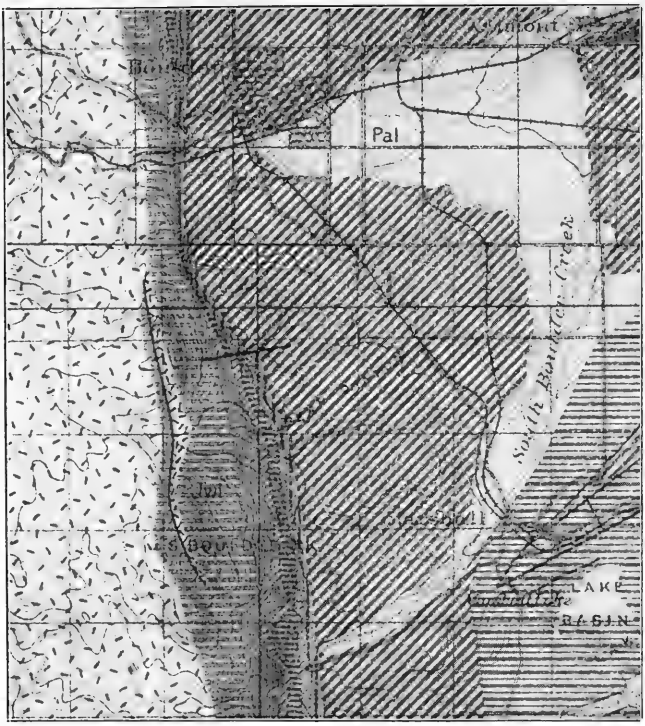


FIG. 1.—The geological formations in order from the left (west) are: (1) Crystallines of the Mountains; (2) Lower Red Beds; (3) Upper Red Beds; (4) Como (Atlantosaurus Beds); (5) Dakota; (6) Benton; (7) Niobrara; (8) Ft. Pierre and Fox Hills; (9) Laramie.

proper to the border of the present flood plains, where in some cases it is terminated by a bluff, while in others it descends in a gentle transition slope not always separable from the mesa-terrace, making one continuous incline from the base of the mesas to the border of the flood plain, into which it passes by imperceptible gradations. Where this transition slope has been

destroyed by the existing streams, and a bluff or steep slope formed, the mesa-terrace impresses one as being possibly due to a former cycle of erosion. But where the transition slope is intact and the surface of the mesa-terrace passes gently into that of the flood plain the two are seen to be obviously due to a continuous process of erosion uninterrupted by any notable change in the attitude of the land.

The substructure of the mesa-terrace is similar to that of the mesas proper, but its surface is more irregular and the covering of fragmental material is not uniform in thickness or in distribution. The mesa-terrace is shown, in part, in the middle foreground of Fig. 2 with the buildings resting upon its surface. The covering of the mesa-terrace differs from that of the mesas, first, in the thinner and more irregular nature of the sheet of débris; second, in the more rounded character of the fragments; and third, in the greater content of crystalline material. The débris on the tops of the mesas contains about 1 per cent. of crystalline material, while the débris on the mesa-terrace is made up of sandstone and crystalline material in varying proportions. The crystalline material of the mesas is chiefly quartz and metamorphic sandstone, such as is contained in the conglomerate of the Red Beds, from which it very probably came, in the main. The crystalline material on the mesa-terrace is largely granitic, and is usually much water-worn and in an advanced stage of decomposition.

At still lower levels is found the sheet of débris which is now gathering over the valley bottoms of the existing streams. These streams are forming wide bottom lands[1] which have a gradient at Boulder of about fifty feet to the mile. In this recent débris the material is imperfectly sorted and is composed largely of crystalline rock from the mountains. The fragments are well rounded and the granitic constituents are not usually decomposed.

In these three stages we find an instructive series; first, the mesa tops, composed mainly of sandstone débris of an angular, slightly worn character; second, on the mesa-terrace the mantle

[1] See Pocket Map, Mon. 27, U. S. Geol. Surv.

has proportionately less sandstone, more metamorphic, and more granitic material, the latter in a much decomposed state; and third, the recent valley drift, composed mainly of well rounded crystalline material of which undecomposed granitic rock forms a large part.

There is one other group of phenomena which must be considered before attempting an interpretation. There is a large mesa near the mouth of Bear Canyon (see map, Fig. 1) on which the largest bowlders are found in great numbers. This mesa is also the highest in the region under discussion. A line drawn from its top, parallel to the foothills and touching the tops of the mesas to the north, would have a gentle slope in that direction, *i. e.*, toward Boulder Creek. A similar though indistinct slope toward South Boulder Creek is indicated by

FIG. 2.—Photograph of the region south of Boulder, from a point north of the city. The surface of one of the mesas and the mesa-terrace appears in the horizon at the left. The point at the extreme right is the peak of Green Mountain, and that in the background is South Boulder Peak.

some remnants south of this mesa. The mesa-terrace has a corresponding inclination.

From the foregoing facts the conditions of formation may be inferred :

1. At the time the mountains began to assume their present elevation they were faced, if not covered, with the sedimentary formations whose truncated edges are now exposed along the foothills. At an early stage of erosion the young streams carried away the shales, since they lay uppermost, and formed the grade upon which the sandstone débris was deposited. The streams found little of a coarse or enduring nature with which to form a deposit and thus prevent the cutting down of the shales to a low gradient until they had cut back into the Red Beds.

2. When the erosion began to work effectively upon these, much coarse and enduring material was loosened and carried down the high gradient of the mountain flank, but the streams were unable to carry all of the coarse parts of it across the lowered gradient of the shale tract, and hence deposited it as the mantle of the present mesa tops.

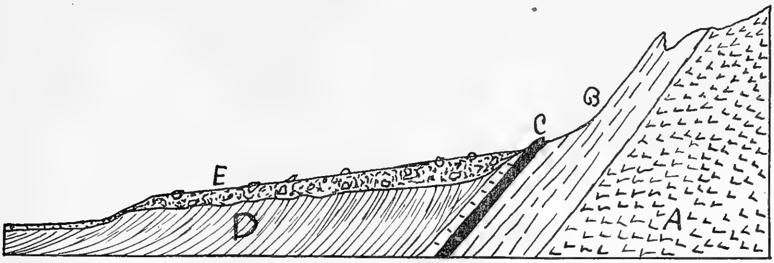
3. As the streams by headward extension reached back into the crystalline area, they derived a less relative amount of material from the Red Beds and more from the crystalline area. Besides, by reaching backward, their gradients had been reduced and they reacquired some eroding power in the mesa zone, and hence cut into it and formed the lower surface — the mesa-terrace — on which is found relatively more crystalline material and relatively less of that from the Red Beds. The granitic material of this mantle being relatively old is much decomposed.

4. The later deposits represent the process carried farther, giving a still larger proportion of crystalline débris, and this, being young, is undecomposed.

At first Bear Creek was an important stream, as shown by the wide gap between Green Mountain and South Boulder Peak. But, for reasons unexplained, Boulder Creek and South Boulder Creek, on either hand, gained in importance at its expense, and

as they more effectually lowered their channels a new grade was produced in the mesa zone, represented now by the mesa-terrace. At the same time this new grade was covered with material formed by a mingling of the old mesa-tops débris with the fresher material from the mountains.

The process of forming the grade and covering it with débris in this manner may be studied in minutest detail at the present day in Boulder Creek Valley. As the present streams are cutting away the mesa-terrace and mingling its fragmental material with



Section of formations shown in FIG. 2.

FIG. 3.

E—Fragmental débris. B—Red Beds.
D—Fort Pierre Shale. A—Crystallines.
C—Dakota.

the fresh material from the mountains, so the more ancient streams undermined the sheet of débris on the mesa-tops and mingled it with that of the then flood plains.

The production of the abrupt slopes forming the sides of the mesas, and to a less extent bounding the mesa-terrace on the one hand, and on the other hand the lateral inclination of the surfaces of both, is well illustrated in Boulder Creek Valley. Before issuing from the crystalline area Boulder Creek has a high gradient and little of its energy is spent in cutting sidewise. Where it passes to the shale formations at Boulder, its gradient becomes lower and much of its energy is spent in cutting laterally. The result is a comparatively slow lowering of the bed of the stream and a comparatively swift migration laterally in the shale region. The migration is at present toward the south. The city

of Boulder is built upon the ground recently abandoned by the stream. A north-south section through the city (see map, Fig. 1), cutting directly across this recently formed grade, shows a slope of the surface to the south of nearly fifty feet to the mile. The tops of the mesas and the surface of the mesa-terrace have an inclination somewhat greater than this but in the opposite direction. It is near the city of Boulder that the most conspicuous slopes are found bordering the mesa-terrace. The transition slope has been cut away and bluffs formed fifty feet high in

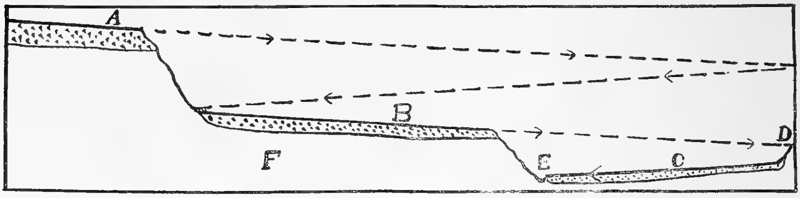


FIG. 4.—Diagrammatic section from the mesa (*A*) south of Boulder City, to the northern border of the present valley bottom, illustrating the assigned origin of the lateral inclinations of the mesa tops, mesa-terrace and valley bottom. *A*=mesa; *B*=mesa-terrace; *C*=valley bottom on which the city stands; *E*=Boulder Creek; *F*=Fort Pierre shale. The dotted lines represent the migrations of Boulder Creek together with the gradual lowering of its bed, the two processes combined producing the northward inclination of the mesa tops and the mesa-terrace, and the southward inclination of the valley bottom.

places. Should this process be continued to the extent of reducing the mesa-terrace to the lateral proportions of the mesas, the transition slopes would all disappear, and the bounding slopes of the mesa-terrace would present essentially the same aspect as those of the mesas. The probable action of the stream in producing the northern inclinations of the mesa-tops and the mesa-terrace together with their bounding slopes, and the southern inclination of the valley bottom by means of lateral migrations is illustrated in Fig. 4.

It is quite impossible to say what influence, if any, surface movement has had in changing the inclinations of the surfaces or determining special features. It seems, however, unnecessary to appeal to such movement, since the phenomena may be

rationally explained by such processes of erosion and deposition as may be witnessed in the same region at the present time.

Conclusions.— From the phenomena observed in this region four conclusions may be drawn: (1) That the accumulations of débris forming the protecting surface of the mesas and the mesa-terrace are of fluviatile origin, and that in their mode of accumulation they differ in no essential respect from that in action over the valley bottoms in that vicinity at the present day. (2) That the mesa tops mark the level of a grade formed by the young streams soon after the adjacent mountains had assumed something like their present attitude. (3) That the three grades represented by (*a*) the mesa tops, (*b*) the mesa-terrace, and (*c*) the present valley bottoms do not seem necessarily to require the assumption of any change in the attitude of the land subsequent to the elevation of the mountains, but are the natural sequences of erosion as influenced by the local distribution and difference in hardness of the formations involved. (4) That the grades were formed and covered with débris by the streams at essentially the same time, and that it is contrary to the observed phenomena to assume that the grading was done at one period and the débris accumulated during some other period.

WILLIS T. LEE.

SUMMARIES OF CURRENT NORTH AMERICAN PRE-CAMBRIAN LITERATURE[1]

CLEMENTS, SMYTH, BAILEY, and VAN HISE[2] describe the Crystal Falls iron-bearing district of Michigan.

The rocks of the district comprise two groups, separated by unconformities. These are the Archean and the Algonkian. The Algonkian includes both the Lower Huronian and the Upper Huronian series, and these are also separated by unconformities. The terms Lower Huronian and Upper Huronian are applied to the series which occur in this district because they are believed to belong to the same geological province as the Huronian rocks of the north shore of Lake Huron, and to be equivalent to the Lower Huronian and Upper Huronian series which there occur.

The Archean is believed to be wholly an igneous group, and therefore no estimate of its thickness can be given. It covers a broad area in the eastern part of the district, and from this several arms project west. West of the main area there are two large oval areas of Archean.

The Lower Huronian series, from the base upward, comprises the Sturgeon quartzite, from 100 feet to more than 1000 feet thick; the Randville dolomite, from 500 to 1500 feet thick; the Mansfield slate, from 100 to 1900 feet thick; the Hemlock volcanic formation, from 1000 to 10,000 or more feet thick; and the Groveland formation, about 500 feet thick. A minimum thickness for the series is about 2200 feet, and a possible maximum thickness is more than 16,000 feet. However, in the latter case, a large part of the series is composed of volcanic material. It is not likely that the sediments at any one place are as much as 5000 feet thick.

The Upper Huronian is a great slate and schist series, which it is not possible to separate on the maps into individual formations. It is impossible to give even an approximate estimate of the thickness of this series.

[1] Continued from page 443, Vol. VIII, JOUR. GEOL.

[2] The Crystal Falls Iron-bearing District of Michigan, by J. MORGAN CLEMENTS and H. L. SMYTH, with a chapter on the Sturgeon River Tongue, by W. S. BAYLEY, and an Introduction by C. R. VAN HISE: Mon. U. S. Geol. Surv., No. XXXVI, 1899. With geological maps.

Various igneous rocks intrude in an intricate manner both are Upper Huronian and the Lower Huronian series.

In the following paragraphs the descriptions of the formations we summarized somewhat more in detail.

The Archean.— The Archean consists mainly of massive and schistose granites and of gneisses. Nowhere in the Archean have any rocks of sedimentary origin been discovered. The Archean has been cut by various igneous rocks, both basic and acid, at different epochs. These occur in the form both of bosses and of dikes, the latter sometimes cutting, but more ordinarily showing a parallelism to, the foliation of the schistose granites. The granites must have formed far below the surface, and therefore must have been deeply denuded before the transgression of the Lower Huronian sea. The Archean granites and gneisses and the earlier intrusives alike have been profoundly metamorphosed, and at various places have been completely recrystallized.

The Lower Huronian series.—The Sturgeon quartzite, the first deposit of the advancing sea, when formed consisted mainly of sandstone, but in places at the base it consisted of coarse conglomerate. The conglomerate is best seen in the Sturgeon River tongue. Elsewhere evidence of conglomeratic character at the base of the formation is seen, but the metamorphism has been so great as nearly to destroy the pebbles. However, in the Sturgeon River tongue is a great schistose conglomerate, which, while profoundly metamorphosed, still gives evidence of the derivation of its material from the older Archean rocks. The sandstone has been changed to a vitreous, largely recrystallized quartzite, which now shows only here and there vague evidence of its clastic character.

The Sturgeon formation varies from probably more than 1000 feet in thickness in the Sturgeon River tongue to less than 100 feet in thickness at places in the Felch Mountain range, and is altogether absent in the northeastern part of the district.

In the southeastern part of the district the Sturgeon quartzite is overlain by the Randville dolomite. In the central part of the district the quartzite between the Archean and the Randville is so thin that it cannot be represented on the maps as a separate formation. In the northeastern part of the district a quartzite, resting on the Archean, but occupying a higher position stratigraphically than the Randville dolomite, is overlain by an iron-bearing formation. It appears,

therefore, that the Sturgeon sea gradually overrode the district, and that at the time the Sturgeon quartzite was deposited in the southeastern part of the area the Archean was not yet submerged in the central and northeastern parts of the district. However, since the quartzite resting on the Archean in the latter area cannot be separated lithologically from the Sturgeon quartzite, both are given the same formation color, but the later quartzite is given a separate letter symbol. The quartzite color therefore represents the transgression deposit of the same general lithological character, rather than a formation all parts of which have exactly the same age. While nowhere in the district is there any marked discordance between the schistosity of the Archean and the Sturgeon quartzite, the conglomerates at the base of the latter formation in the Sturgeon River tongue are believed to indicate a great unconformity between the Archean and the Lower Huronian series. The change from the Sturgeon deposits to those of the Randville was a transition.

The Randville dolomite is a nonclastic sediment, and is believed to mark a period of subsidence and transgression of the sea to the northeast, resulting in deeper water for much of the district. Since the Randville dolomite has its full thickness on the Fence River just east of the western Archean oval, and does not appear at all about the Archean oval a short distance to the northeast, it is probable that the shore line, during Randville time, was between these two areas and that the land arose somewhat abruptly toward the northeast. As the Randville formation has a thickness of 1500 feet, it probably represents a considerable part of Lower Huronian time.

Following the deposition of the Randville dolomite, deposits of very different character occur in different parts of the district. These deposits are: (1) The Mansfield formation, (2) the Hemlock volcanic formation, and (3) the Groveland formation.

The Mansfield formation was a mudstone, which has subsequently been transformed into a slate or schist. The Hemlock formation is mainly a great volcanic mass, including both basic and acid rocks, lavas, and tuffs, but it contains also subordinate interbedded sedimentary rocks. This formation occupies a larger area than other of Lower Huronian formation, and is perhaps the most characteristic features of the Crystal Falls district. The Groveland is the iron-bearing formation. It includes sideritic rocks, cherts, jaspilites, iron ores, and other varieties characteristic of the iron-bearing formations

of the Lake Superior region. In all important respects these rocks are similar to those of the Negaunee formation of the Marquette district, with the exception that in the southeastern part of the Crystal Falls district, associated with the nonclastic material, there is a considerable proportion of clastic deposits. The Groveland formation contains iron carbonate and possibly glauconite, from which its other characteristic rocks were derived.

The variability in the character of the deposits overlying the Randville formation is probably caused by the great volcanic outbreaks in the western part of the district. In the southern and southeastern parts of the area the deposit overlying the Randville formation is the Mansfield slate and schist. North of Michigamme Mountain and of the Mansfield area the Mansfield formation is replaced along the strike by the Hemlock volcanic formation, which directly overlies the limestone for most of the way about the western Archean oval. The effect of the volcanic outbreak apparently did not reach so far as the northeastern part of the district.

Overlying the Mansfield formation in the southeastern part of the district and the Randville formation in the central part of the district is the Groveland iron-bearing formation. In the Mansfield slate area the iron-bearing rocks appear near the top of the Mansfield formation intercalated with the slates. The Groveland formation cannot be certainly traced farther north than the northeastern portion of the western Archean oval. It is apparently replaced along the strike by the Hemlock volcanics.

In the northeastern part of the district the Groveland formation, equivalent to the Negaunee formation of the Marquette district of Michigan, is found above the Ajibik formation. The occupation, in the western part of the district, by the Hemlock volcanics of the same part of the geological column as occupied by the Hemlock volcanics east of the western Archean oval, the Mansfield slate, and the Groveland formation, is explained by the fact that in the western part of the district the volcanoes broke out and there continued their activity longest. While north of Crystal Falls the volcanic rocks were laid down, the Mansfield formation was being deposited in the southeastern part of the district. This activity continued there through the time in which the Groveland formation was being deposited in other parts of the district.

From the foregoing it appears that the Hemlock formation in the western part of the district is equivalent:

1. East of the western Archean oval, to the Hemlock volcanics found there and the overlying Groveland formation.

2. At Michigamme Mountain, to the Mansfield slates and the Groveland formation.

3. In the Mansfield area, to the Mansfield slates and the Hemlock volcanics occurring there.

4. In the southeastern part of the district, to the Mansfield and Groveland formations.

The replacement of an iron-bearing formation by the great volcanic formation just described is exactly paralleled in the Upper Huronian rocks of the Penokee iron-bearing series, where the pure iron-bearing formation is replaced at the east end of the district by a great volume of volcanic rocks intercalated with slates and containing bunches of iron-formation material.

Following the deposition of the Lower Huronian series, the region was raised above the sea and eroded to different depths in different places. In the Felch Mountain range the only formations above the Randville dolomite are a thin bed of slate and the Groveland iron formation. In the northeastern part of the district only a thin belt of iron-formation rocks remains. In the central and western parts of the district there is a great thickness of volcanics. This, however, does not imply a difference of erosion equal to the difference in thickness of these rocks, for doubtless when the volcanics were built up there was contemporaneous subsidence, so that at the end of Lower Huronian time there may have been little variation in the elevation of the upper surface of the series, but very great differences in its thickness.

The Upper Huronian.— After the Lower Huronian series was deposited the district was raised above the sea, may have been greatly folded, and was eroded to different depths in different parts of the district.

Following the earth movements and erosion, the waters for some reason advanced over the district, and the Upper Huronian series was deposited. The basal horizon was a conglomerate, which has, however, very different characters in different parts of the district.

In the eastern half were Archean rocks, the Sturgeon quartzite, the Mansfield slate, and the Groveland iron formation. Upon these was deposited a sandstone which locally was very ferruginous. This has

subsequently been changed iuto a ferruginous quartzite. The typical occurrence of this quartzite is at the end of the Felch Mountain range. It also appears between the Archean ovals in the northeastern part of the district. If distinct conglomerates were formed at the bottom of this quartzite, they are buried under glacial deposits or have disappeared as the result of metamorphism.

In the western part of the district the rocks of the Lower Huronian at the surface are the great Hemlock formation, and here the basal horizon of the Upper Huronian is a slate or slaty conglomerate, the fragments of which are derived mainly from the underlying Hemlock formation. The sandstones and conglomerates varied upward into shales and grits, which have been subsequently altered into mica-slates and mica schists. After a considerable thickness of mudstone and grit was deposited, there followed a layer of combined clastic and non-clastic sediments, the latter-including iron-bearing carbonates. These appear to be at a somewhat persistent horizon, and in this belt are found the iron-formation rocks, and iron ores in the Upper Huronian in the vicinity of Crystal Falls. Above these ferruginous rocks there was deposited a great thickness of shales and grits which have been transformed into mica-slates and mica-schists.

Since the deposition of the Upper Huronian the rocks of the district have been folded. The more complex folds vary from a north-south to an east-west direction. The closer folds in the northeastern part of the area are nearly north-south. In the central part of the area the closer folds strike northwest-southeast. In the eastern and southeastern parts of the district the closer folds are nearly east-west. All of these folds have steep pitches.

Subsequent to, or during the late stage of, this time of folding there was a period of great igneous activity, probably contemporaneous with the Keweenawan. At this time there were introduced into both the Lower and Upper Huronian vast bosses and numerous dikes. The intrusives vary from those of an ultrabasic character, such as peridotites, through those of a basic character, such as gabbros and dolorites, to those of an acid character, such as granites. These intrusives, while altered metasomatically, do not show marked evidence of dynamic metamorphism ; therefore the conclusion that they were introduced later than the period of intense folding already described.

Cambrian rocks overlie unconformably the rocks above described.

DESCENDING SUCCESSION OF FORMATIONS IN THE MARQUETTE, CRYSTAL FALLS, AND MENOMINEE DISTRICTS.

MARQUETTE DISTRICT	CRYSTAL FALLS DISTRICT	MENOMINEE DISTRICT
UPPER MARQUETTE	UPPER HURONIAN	UPPER MENOMINEE
1. Michigamme formation, bearing a short distance above its base an iron-bearing horizon, and being replaced in much of the district by the Clarksburg volcanic formation.	1. Michigamme formation, bearing a short distance above its base an iron-bearing horizon.	1. Great Slate formation.
2. Ishpeming formation, being composed of the Goodrich quartzite in the eastern part of the district, and of the Goodrich quartzite and the Bijiki schists in the western part of the district.	2. Quartzite in eastern part of the district.	
Unconformity	Unconformity	Unconformity
LOWER MARQUETTE	LOWER HURONIAN	LOWER MENOMINEE
1. Negaunee iron formation, 1000 to 1500 feet.	1. The Groveland formation, about 500 feet thick.	1. Vulcan iron formation containing slates.
2. Siamo slate, in places including interstratified amygdaloids, 200 to 625 feet thick.	2. Hemlock volcanic formation, 1000 to 10,000 feet thick. In western part of district also occupies place of (1) and (3).	2. Antoine dolomite.
3. Ajibik quartzite, 700 to 900 feet.		
4. Wewe slate, 550 to 1050 feet.	3. Mansfield formation, 100 to 1900 feet thick.	
5. Kona dolomite, 550 to 1375 feet.	4. Randville dolomite, 500 to 1500 feet thick.	
6. Mesnard quartzite, 100 to 670 feet.	5. Sturgeon quartzite, 100 to 1000 feet thick.	3. Sturgeon quartzite.
Unconformity	Unconformity	Unconformity
ARCHEAN	ARCHEAN	ARCHEAN

Lane[1] gives a detailed account of the geology and petrography of Isle Royale, Lake Superior. The island trends north of east and the edges of the strata outcrop in approximately this direction. The rocks are interbedded conglomerates, sandstones, and traps of Keweenawan age, dipping in a southerly direction at angles varying from 8–32°, the higher dips in general to the north. Faults are shown to exist at various places with directions approximately northeast–southwest and northwest–southeast, and the probable existence of other more extensive faults running entirely across the island is indicated. The detailed sections with correlations with the Keweenawan of other parts of Lake Superior are given in table on page 520.

Hubbard[2] discusses the geology of Keweenaw Point with particular reference to the felsites and their associated rocks. The term felsite is used to include all the very fine-grained and highly acid igneous rocks. These occur at a number of horizons below the Bohemian conglomerate, so-called from the fact that it skirts the northern side of this range near the northeastern end of Keweenaw Point. The outcrops of felsite studied occur in Sec. 30, T. 58, R. 27 (New England or Keystone location); Sec. 25 (?), Sec. 35 (Fish Cove), Secs. 26 and 27 (Little Montreal River), all in T. 58, R. 28; Secs. 29 and 30, T. 58, R. 28 (Bare Hill and westward therefrom) Secs. 23 and 24, T. 58, R 29 (Mt. Houghton) and both eastward and westward therefrom; Sec. 10, T. 57, R. 31 (Suffolk location, Praysville); Sec. 4, T. 56, R. 32 (Allouez Gap, east of the Kearsage and Wolverine mines); Sec. 30, T. 56, R. 32 (falls on branch of Trap Rock River); Sec. 36, T. 56, R. 33 (Douglass Houghton Falls), and Sec. 1, T. 55, R. 33 (Hecla and Torch Lake R. R).

The evidence concerning the source of the Keweenawan lavas is considered and it is concluded that they may probably have come from a higher level somewhat back from the edges of the present Keweenawan basin.

With this probability in mind, the following hypotheses are suggested:

1. The irregularities in the lower beds of the Keweenaw series in the Portage Lake area, contrasted with the greater regularity of the

[1] Geological Report on Isle Royale, Michigan, by A. C. LANE: Geol. Surv. of Mich., Vol. VI, 1898, Pt. 1, pp. 1–281. With geological map.

[2] Keweenaw Point with Particular Reference to the Felsites and their Associated Rocks, by L. L. HUBBARD: Geol. Surv. of Michigan, Vol. VI, 1893–1897, Pt. 2, pp. 184. With plates.

Name		Depth in drill hole, feet	Total thickness from 0 feet	Number in Eagle River section	Thickness in Eagle River Section	Copper Falls section	Tamarack section	Conglomerate numbers	Distances	Minnesota correlations
Upper sandstone and conglomerate		....	2600	2500	....	....	....	....	....	....
First known trap	Marvine's (c)	0	0	No. 1	....	....	....	....	....	Temperance River group ?
Ophites, numerous sandstones		....	....	....	....	....	....	....	....	
Island mine conglomerates		170	567	35	1146	1035	2146	18 ?	....	
Transition flows, porphyrite and ophite		193	589			1012				
		415	806	44	1417	745	2021	17	....	
Scoriaceous conglomerate	Marvine's (b)	426	817							
Green porphyrites		279	1100	63	1810	368	1639	17	853	
Scoriaceous conglomerate "Ashbed"		291	1112	65	....	....	....		885	
		....	....	....	2035	160	....	....	....	
Porphyrites	Marvine's (c)	....	....	....	....	0	....	....	....	
Red sandstone		377	1526	80 ?	2432	495	1081	16	1435	
Porphyrites, etc		419	1567		2496	500	1053		1445	
Felsite tuff		81	2035	....	....	....	160	*	....	Beaver Bay group ?
		91	2045	....	....	....	....	....	....	
Ophite, and the thickest ophite—the Green-		....	....	90	2840	Central mine	....	....	....	
stone Conglomerates — the Allouez or		....	....	108	4120		....	....	....	
"Slide"		363	2310	....	....	0	0	15	2345	Agate River group ?
		386	2332	....	....				2378	
Amygdaloids mainly and thin ophites		136	2570 ?	....	....	660	....	14	....	
		175	....	....	....	....	....			
		133	3197	....	....	1474	1309	13	....	
		....	....	....	....	....	....	12	....	
Minong breccia		386	4030						4853	
Minong porphyrite		426	4068	"Kingston" or Kearsarge ?		2599	2239	11	4873	
Minong trap		456	4097							
		536	4174							
Various beds ending with a thick ophite		....	....	....	....	....	....	....	....	
Huginnin porphyrite		367	5194							
		436	5260							
Ophites										
Felsitic conglomerate		475	5868					6	7643	
		487	5879							
Various igneous flows and conglomerates		....	....	....	....	....	....	....	....	
Felsitic conglomerate and felsite tuff		786	6155							
		910	6267							
Felsite		....	6400	Praysville		....	....	....	....	

* 67.7 above Allouez at Peninsula mine.

higher part of the series, suggest that in this area, near the contact between the Keweenaw series and the Eastern sandstone, we are on the edge of an early-Keweenawan or pre-Keweenawan basin.

2. If the lower beds of the Keweenaw series near Portage Lake rested on the sides of a basin, the later beds of the series from here eastward lay at a higher altitude and, excepting those of the South Trap Range, were eroded in pre-Potsdam time together, possibly, with a part of the underlying Archean.

3. The porphyries found on Keweenaw Point at the contact between the Keweenaw series and the Potsdam sandstone may be in part either,

a. Marginal facies of the underlying Archean;

b. Intrusive in the early Keweenawan;

c. Early interbedded flows of the Keweenaw series; or,

d. Remnants of late Keweenawan intrusions by which the eastern margin of the series was broken up and its degradation hastened.

Seaman[1] gives a summary of the geological history of the Keweenawan copper range in Michigan, Wisconsin, and Minnesota. No new point on the geology of the region is added to those already recorded.

Hall[2] describes the pre-Cambrian crystalline rocks of the Minnesota river valley of southwestern Minnesota. These rocks appear in numerous exposures along the river, protruding from the drift, from southeast of New Ulm to Ortonville on the northwest. The great bulk of the crystalline rocks are granites and gneisses. These appear for the most part in the river bottoms, but stand also in a few isolated knobs on the higher ground south and west of the river. There are many varieties of granites and gneisses and all gradations between them. They are taken as a whole to represent the Archean or Basement complex.

Associated with the granites and gneisses are a much smaller number of exposures of gabbros and gabbro-schists. These present many varieties, all of which are believed to have resulted from the alteration of two original forms and their intergradations—a hypersthene-bearing gabbro and a hypersthene-free gabbro.

[1] Geology of the Mineral Range, by A. E. SEAMAN: First Ann. Rept. of the Copper Mining Industry of Lake Superior, 1899, pp. 49–60.

[2] The Gneisses, Gabbro-Schists and Associated Rocks of Southwestern Minnesota, by C. W. HALL: Bull. U. S. Geol. Surv., No. 157, 1899, pp. 131. With geological maps.

Peridotite is found in one exposure only in this valley, three miles southeast of Morton. The relations to the other rocks of the area could not be determined. Cutting the gneisses and gabbro-schists throughout the area are numerous dikes of diabase. They vary in width from a fraction of an inch to 175 feet. Their age is probably Keweenawan.

Southeast of Redstone and near New Ulm are exposures of quartzite associated with coarse quartzite conglomerate. Near Redstone the strike of the quartzites is N. 60–70° W., and their dip varies from 5–27° N. In New Ulm the strike is N. 15° E., and the dip varies from 10–15° S. E. The quartzite is believed to be the same as the quartzite found in a deep well at Minneopa Falls, near Mankato, Minn., which is covered by a quartzite conglomerate of Middle Cambrian age. The quartzite of Redstone and New Ulm is above the Archean granite and gneiss. It is believed to be of Huronian age, but whether Upper or Lower is unknown.

Overlying the crystalline rocks are Cretaceous shales and sandstones, which appear in rare exposures in the valley, and glacial drift.

Coleman[1] discusses areas mapped by Logan as Huronian north of Lake Huron and the east end of Lake Superior. The two contacts described by Irving and Van Hise as contacts of the Lower Huronian and Laurentian rocks were examined. At the first, on the islands four miles east of Thessalon, jasper and chert fragments were found in the conglomerate above the Laurentian, indicating that the conglomerate is probably a part of an upper series, younger than a series of rocks, not Laurentian, from which the jasper must have been derived. At the other contact, on the road between Sault Ste. Marie and Garden River, it is concluded that the conglomerate is possibly a crushed conglomerate formed by faulting instead of a water-formed rock.

Certain green and gray schists inclosed in the Laurentian gneisses are believed to represent the western Keewatin of Lawson.

The Laurentian and Huronian contact at Goulais and Batchawana bays was found to be in general of the nature of an eruptive contact, although a clear example of the inclusion of a typical Huronian rock in the Laurentian was not observed.

The slate-conglomerate of Doré River contains no bowlders that are distictly Laurentian. It contains only fragments of schists and

[1] Copper Regions of the Upper Lakes, by A. P. Coleman: Rept. of the Bureau of Mines, Ontario, Vol. VIII, Pt. 2, 1899, pp. 121–174.

eruptives from rocks which have been called Huronian. It probably has closer affinities to Lawson's Keewatin than to Logan's Original Huronian.

On the shores of Heron Bay the schist-conglomerate and slate were examined. The conglomerate contains fragments mainly of granite. These rocks are more closely allied to the Keewatin than to the Original Huronian type.

In general it is believed that Logan mapped as Huronian, rocks which are really Huronian and Keewatin.

The ascending succession for the region as indicated by the above facts is as follows: Keewatin, consisting mainly of basic green-schists; Laurentian, consisting mainly of moderately acid eruptives; and Huronian. The term Laurentian is confined to areas of granite and granitoid gneiss corresponding to the Ottawa Gneiss of eastern Canada, and having eruptive relations to the Keewatin.

The Keweenawan rocks of the various area on the north shore of Lake Superior were studied, but no important conclusions were reached differing from those of Irving. One variety of conglomerate, made up chiefly of underlying Laurentian rocks is common on the north shore, which apparently has not been found on the south shore.

Comments.—This discussion points toward the conclusion that the Original Huronian rocks of Logan are largely a series above and later than certain rocks to the west mapped by Logan as Huronian, and other rocks still farther to the west mapped by Lawson as Keewatin; further that the Laurentian rocks intrude the earlier series, and are unconformably overlain by the later Original Huronian series of Logan.

That the Original Huronian, in large part, is younger than some of the Keewatin rocks of Lawson is possible. The finding of chert and jasper fragments in the conglomerate cited by Irving and Van Hise as Lower Huronian would show that more of the series belongs to an upper division than was supposed.

However, as Dr. Coleman himself would fully agree, there still remains evidence to indicate that rocks of both Upper and Lower Huronian series are present in the Original Huronian area, and for the Keewatin of Lawson the evidence is conclusive that two or more series are represented. In view of this wide range of rocks in both areas, and the wide separation of the areas it is unsafe at present to make a definite statement concerning the relative ages of Lawson's Keewatin

and Logan's Original Huronian, based on lithological character and relations to the intrusives.

Dr. Coleman's conception of the Laurentian is the same as that attributed to the Canadian geologists in general in the comments on p. 440.

McInnes[1] describes the geology of the Seine River and Lake Shebandowan map-sheets, which cover an area extending west and northwest of Port Arthur, Ontario. Laurentian granites and gneisses with many variations occupy three fourths of the area. The relations to the overlying Keewatin and Coutchiching rocks, wherever they have been found in contact, have been those of intrusion.

The Huronian is represented by Coutchiching and Keewatin rocks.

Coutchiching mica-schists and fine-grained gneisses, a continuation of Lawson's Coutchiching in the Rainy River district to the west, enter the area of the Seine River sheet on the west side. However, toward the east these rocks become associated with large quantities of gneisses, and for the eastern two thirds of the Seine River sheet and for the entire Lake Shebandowan sheet the gneisses are predominant and the belt is mapped as Laurentian. In other parts of the district the Keewatin schists, near their contact with the Laurentian gneisses, assume a character exactly similar to the Coutchiching schists and associated gneisses, and could not be lithologically distinguished. Indeed, the Coutchiching seems to be an extremely altered phase of the Keewatin.

In long bands infolded with the Laurentian and conforming in strike with the foliation of the gneiss are bands of Keewatin rocks varying greatly in width. They vary in composition from extremely basic igneous masses, and their derived products, to acid quartz-porphyries, and their derived products, and include also quartzites, conglomerates, and slates. The basic rocks form the largest volume of the rocks of the series. The series is separated lithologically in mapping into three divisions. There can be no doubt that the Keewatin here includes rocks which are of widely differing age.

Overlying unconformably the Keewatin rocks is the Steep Rock Lake series, so named from its occurrence in the neighborhood of this lake. The series is mapped as an upper division of the Keewatin series. As

[1] "The Geology of the Area Covered by the Seine River and Lake Shebandowan Map-Sheets, comprising Portions of Rainy River and Thunder Bay Districts, Ontario," by WM. MCINNES: Ann. Rept. Geol. Surv. of Canada, Vol. X, Pt. H, 1899, pp. 13–51. With geological map.

described by Smyth it comprises conglomerate, limestone, clay-slate, and various basic volcanic and intrusive rocks. Because of the folding of the series it is believed to be older than the Animikie strata of Thunder bay.

Animikie rocks occur in a small area in the southeast corner of the Shebandowan sheet. They overlie unconformably the Keewatin and Laurentian rocks, and from their stratigraphical relations to the overlying formation farther east on Lake Superior they are believed to be of Lower Cambridge age.

Comments.—The mapping of this area of these sheets has been largely lithological, the red granites and gneisses and their associated rocks of various ages being mapped as Laurentian, and the green rocks and the associated sedimentaries being mapped as Huronian. However, a distinct advance is made in seeing that some of the Coutchiching rocks are no more than metamorphosed Huronian or Keewatin rocks. This is a frank awowal that the Coutchiching series is a lithological, not a structural unit.

The Steep Rock Lake conglomerate was considered by Smyth and Pumpelly as the basal portion of the Lower Huronian, and the underlying rocks as Archean. McInnes has mapped the underlying rocks as Keewatin, and has included in them sedimentary and igneous rocks. He has not separated from them sedimentary rocks which may be the equivalent of the Steep Rock series.

C. K. LEITH.

Studies for Students

RESULTS OF TESTS OF WISCONSIN BUILDING STONE III[1]

In this the concluding paper on the testing of building stones I will summarize and discuss various tests which I made in the laboratory of the Wisconsin Geological Survey during the winter of 1897–8.

In examining the tests recorded in some of the reports on building stones I found them to be really of little value, either on account of the failure of the operator to describe carefully the methods employed in making the tests or owing to insufficient care in manipulation and computation. It has been noted that among sedimentary rocks the results of tests on samples from different parts of the same quarry may be very different. Such differences may be even more marked than those that occur between samples from different quarries within the same area. It is possible to select samples from a quarry which will give very high tests, while a greater part of the stone may be of the poorest kind. Valuable results can only be obtained when tests are made upon samples which are a fair average of the stone as it occurs in the quarry.

For making the tests herein discussed, the author endeavored to obtain samples which represented as nearly as possible average No. 1 stone. The tests were performed as nearly as possible in accordance with the instructions laid down in the previous paper. The utmost care was exercised in obtaining truthful results, and it is believed that the figures given are nearly accurate for the samples tested.

[1] The illustrations accompanying this paper are used by permission of the director of the Wisconsin Geological and Natural History Survey. A fuller discussion of these tests will be found in Bulletin No. IV of the Wisconsin Geological and Natural History Survey reports.

CRUSHING STRENGTH

The individual test which is employed perhaps more than any other to determine the strength and durability of a stone is the crushing strength test. For years certain architects and builders have relied upon this test almost exclusively for forming an estimate of the suitability of a stone for all kinds of public and private buildings. This general use of the crushing strength test is still prevalent in some sections of the country.

In order to be assured of the reliability of the machine in which the crushing strength tests were to be made, comparisons were made with tests made in two other machines on samples from the same quarries. One of the machines used was also calibrated to give positive assurance of its reliability. In making the tests, note was taken of the position of the sample in the machine with respect to bedding or schistosity.

Twenty-seven samples of granite from twelve different quarries were tested. The lowest crushing strength obtained was 12,704 pounds per square inch, while the highest was 47,674 pounds per square inch. The average crushing strength of all the samples tested was 27,023.7 pounds per square inch. The minimum crushing strength was above the maximum crushing strength obtained for sandstone, and was obtained on a sample of granite gneiss in which the lamination was diagonal to the direction of the pressure. As far as my knowledge extends the maximum crushing strength is the highest yet recorded for any rock tested in the United States. It was obtained from a sample of rhyolite on which the pressure was applied normal to the head or in the direction of the rift.

It has been generally supposed that the crushing strength of a stone is least in the direction of the rift or lamination, but apparently this is not true in the case of the rhyolite in question. This rhyolite consists of elongated crystals of feldspar and other minerals in a very dense groundmass, forming what one might consider a very compact bundle of fibers. A rock with such a structure can apparently sustain a greater pressure when applied in the direction of these fibers than when applied across them.

Further, a careful examination of the polished faces of this rock shows that the feldspar crystals are broken by numerous cross fractures. These small, scarcely perceptible fractures may account in part for the less load which the rock is capable of sustaining normal to the rift. The cone which remained after crushing this sample of rhyolite is shown in Plate I.

The highest crushing strength obtained for true granite was 43,973 pounds per square inch, which was obtained on a sample of the Montello stone. This, so far as my knowledge goes, is the highest crushing strength that has been recorded for any United States granite. It exceeds the highest test on the Fourche Mountain granite[1] of Arkansas by nearly 15,000 pounds per square inch, while the highest test on the granite from St. Cloud,[2] Minn., is 16,000 pounds less than this. The granite from Redgranite, Waushara county, also gave a crushing strength of over 36,000 pounds per square inch, which exceeds the highest test made on the Fourche Mountain granite by 7000 pounds per square inch. These illustrations give evidence that in at least three different areas in Wisconsin granite and rhyolite occur, which, as far as known, surpass in strength granite or rhyolite from any other quarry in the United States.

Most of the granite samples broke with an explosion. Ordinarily an upper pyramid or cone, such as shown in the accompanying illustration, Plate I, was all that remained after the test. In a few cases a lower or opposite pyramid remained, but as a rule this part of the sample was reduced to powder. In many of the cones that remained a concentric structure had been developed through the pressure, which had much the appearance of cleavage. This is nicely shown in the accompanying illustration, Plate II.

Thirty-one tests were made on limestone from eleven different quarries. The strongest sample tested gave a crushing strength of 42,787 pounds per square inch, which is about 18,000 pounds higher than any known test recorded for limestone,

[1] Annual Report Arkansas Geological Survey, 1890, Vol. II, p. 42.

[2] Geological and Natural History Survey of Minnesota, 1884, Vol. I, p. 196.

dolomite, or marble in the United States. The stone which gave this test was a thoroughly crystalline, well compacted, and homogenous dolomite. The weakest sample tested gave a crushing strength of a little over 6600 pounds per square inch. The strength of the weakest limestone is very little less than that of the ordinary sandstones tested. The sample which gave the highest test was from the Marblehead Lime and Stone Company's quarry in the Niagara formation. Other samples from the Niagara formation gave tests of 39,983 pounds, 36,731 pounds, 33,485 pounds, 32,171 pounds, and 31,800 pounds per square inch.

The crushing of the samples of limestone was ordinarily accompanied with less noise than the granite. Occasionally the samples scaled off along the edges and corners before the maximum load was applied. In some cases two pyramids were developed, but as a rule, only one remained after crushing the more perfectly prepared cubes. The pyramids resulting from the crushing of limestone are ordinarily much steeper and more slender than those of the granite. Occasionally wedge-like forms were developed which resembled the wedge-shaped pyramids of the granite, as shown in Plate II, Fig. 2 and Plate IV, Fig. 3. Occasionally the samples are reduced to splinters, even the pyramids falling in pieces when raised from the steel plate. The cone which remained after the "record sample" of limestone was crushed is shown in Plate III, Fig. 6. Other typical pyramids resulting from crushing limestone samples are shown in Plate III, Figs. 1–5.

The crushing strength was determined for forty-five samples of sandstone from eleven different quarries. The samples from several of the quarries were thoroughly indurated while others were very soft and incoherent. In most cases the cementing material was silica but in some of the weaker samples iron oxide was the principal bonding constituent. Compared with the strength of the granite and limestone, the sandstone may be considered relatively weak. The sample which gave the highest strength test was from the quarry of the Chicago and

Northwestern Railway Company at Ablemans. This sample gave a test of 13,431 pounds per square inch. The lowest test was 1658 pounds per square inch, made on a sample of Lake Superior brown sandstone tested on edge. The lowest test across the bed was 2502 pounds made on a sample of Dunnville sandstone. The average strength of all the sandstone samples tested, one half of which were on edge and the other half on the bed, was 6361 pounds per square inch. The average crushing strength of twenty tests of the Lake Superior brown sandstone, one half of which were on edge and the other half on the bed, was 4618 pounds per square inch. This is a somewhat higher average crushing strength than that recorded for the Bedford öolitic limestone of Indiana.[1]

The weaker the sandstone and the more uniform the grains, the more perfect are the pyramids which develop. In the stronger samples the pyramidal form is replaced by the conical. In the samples of moderate strength almost perfect pyramids form on both the upper and lower sides, as shown in the accompanying illustration, Plate IV, Figs. 1 and 4.

In performing these tests my attention was called to the fact that the crushing strength on edge of the weakest samples was considerably less than that on the bed, while in the stronger rocks the difference was much less. The compressive strength of several different limestones was higher when the pressure was applied along the bed than when applied across it. The Berlin rhyolite, which is the strongest stone tested, gave the highest strength test when the pressure was applied in the direction of easiest parting. These results indicate that there are exceptions to the general rule that a stone will withstand the greatest pressure when applied normal to the bed. Apparently the rule applies only to stone which has a low compressive strength. When the compressive strength is very high the opposite result is fully as likely to occur and may even prove the rule.

The manner in which the cubes of stone break indicates to a greater or less extent the strength of the stone. Crushing a

[1] Twenty-first Annual Report of the Indiana Department of Geology and Natural Resources, p. 317.

stone which has a compressive strength of less than 10,000 pounds per square inch usually results in the formation of two quite well defined pyramids. The pyramids resulting from crushing a stone with a compressive strength of between 10,000 and 20,000 pounds per square inch are ordinarily less perfect. The pyramids resulting from testing stone of this class are frequently wedge-shaped but more often they are intermediate between a pyramid and a cone. The crushing of cubes having a compressive strength of over 30,000 pounds per square inch usually results in the formation of only one pyramid which has more of a conical than pyramidal outline.

In crushing the granite and also some of the limestone and sandstone cubes a concentric structure was developed similar to that illustrated in Plate II, Figs. 4, 5, and 6.

TABLE I.

CRUSHING STRENGTH[1]

Ultimate Strength in Pounds per Square Inch.

	Highest test	Lowest test	Average
Granite and rhyolite: twenty-seven samples from twelve different quarries	47,674	12,704	27,023.7
Limestone: thirty-one samples from eleven different quarries	42,787	6,675	25,312.8
Sandstone: forty-five samples from eleven different quarries	13,699	1,658	6,125.0

TRANSVERSE STRENGTH

The determination of the modulus of rupture is of as great if not greater importance than the crushing strength. As previously indicated, it is especially valuable in determining the required thickness of a stone which is intended to be supported at the ends, and which carries a heavy weight of superstructure in the middle.

The modulus of rupture was determined for only two Wisconsin granites. The results in each case were over 2300 pounds

[1] For detailed results of individual tests see Bulletin No. IV, Wisconsin Geological and Natural History Survey, "Building and Ornamental Stones," 1898.

per square inch. The average transverse strength of the Montello granite was over 3780 pounds per square inch. The samples broke suddenly, and the fracture extended diagonally across the center of the pieces.

The modulus of rupture was determined for samples of limestone from eight different quarries. The results ranged from 1164.3 pounds to 4659.2 pounds per square inch. The highest result obtained was on a sample of stone from the Laurea Stone Company's quarry at Sturgeon Bay. The stone from the Marblehead Lime and Stone Company's quarry at Eden gave a modulus of rupture of 3632 pounds per square inch. All of the transverse strength tests were high. The samples broke very close to the center and much quieter than the granite.

The modulus of rupture was determined for sandstone from six different quarries. The results ranged from 362.9 pounds to 1324 pounds per square inch. The highest test obtained was on samples from the Chicago & Northwestern Railway Company's quarry at Ablemans. Eight tests of the brown sandstone from the Lake Superior region gave an average modulus of rupture of about 500 pounds per square inch.

A comparative examination of the results shows that the finely crystalline limestone possesses a higher modulus of rupture than either the sandstone or granite. However, it is ordinarily less rigid than either of these stones, and is more liable to sag when suspended at the ends.

TABLE II

TRANSVERSE STRENGTH

Modulus of Rupture in Pounds per Square Inch

	Highest test	Lowest test	Average
Granite and rhyolite: four samples from two different quarries.	3,909.7	2,324.3	3,156.2
Limestone: ten samples from eight different quarries.	4,659.2	1,164.3	2,761.15
Sandstone: sixteen samples from six different quarries.	1,324	150.2	558.8

MODULUS OF ELASTICITY

Up to the present time very few determinations of the modulus of elasticity have been made, especially in the United States. However, a knowledge of the modulus of elasticity is of value to architects and builders in many of their calculations.

The modulus of elasticity was determined for granite from eleven different quarries. The results varied between wide limits, ranging all the way from 156,000 pounds to 2,070,000 pounds per square inch. The first result is comparatively low, while the latter is very high. Four samples of granite from Wausau gave tests of from 1,040,000 to 1,815,000 pounds per square inch. The Athelstane granite from Amberg tested very close to 1,000,000 pounds per square inch. The Pike River gray granite from the same place tested nearly 1,500,000 pounds per square inch.

The modulus of elasticity was determined for limestone from four different quarries. The results obtained varied from 31,500 pounds per square inch to 869,400 pounds per square inch. The highest result was obtained for limestone from the Washington Stone Company's quarry which is located at Sturgeon Bay.

The modulus of elasticity was determined for samples of sandstone from ten different quarries. The results of these tests varied from 32,000 pounds to 400,800 pounds per square inch. The highest result was obtained for samples of white sandstone from the Chicago & Northwestern Railway Company's quarry at Ablemans. The modulus of elasticity of the Lake Superior brown sandstone ranged from 56,000 to 387,900 pounds per square inch.

In general it will be noted that the modulus of elasticity corresponds approximately with the crushing and transverse strength of the different rocks tested. The crushing strength, transverse strength, and modulus of elasticity were all lower for the sandstone samples tested than for either the limestone or granite.

TABLE III

MODULUS OF ELASTICITY

In Pounds per Square Inch

	Highest test	Lowest test	Average
Granite and rhyolite: twenty-one samples from eleven different quarries	2,070,000	156,000	1,068,634
Limestone: eleven samples from five different quarries	1,835,700	31,500	786,145
Sandstone: twenty-eight samples from ten different quarries	400,800	32,000	163,861

HARDNESS

The hardness of a stone can be easily determined with the abrading machine known as the Deval.[1] For making this test a definite quantity (5 kg) of cubical pieces of stone from two to two and one half inches in diameter are placed in one of the cylinders of this machine, which is then rotated for five hours at a rate of about thirty-three revolutions per minute. The percentage of dust which is worn off by this treatment is the measure of the hardness of the stone. The coefficient of wear, which is another and the usual method of expressing the hardness, is computed from the following formula:

$$Q=\frac{20 \times 20}{W},$$

in which

Q = the coefficient of wear
W = the quantity of dust formed.

Two samples of granite from each of two quarries were tested in the abrading machine, with the results given in Table IV. Quartzite from one quarry, trap rock from one quarry, and limestone from seven quarries were also tested, with the results given in Table IV.

TABLE IV

HARDNESS OR COEFFICIENT OF WEAR

	Highest	Lowest	Average
Granite: four samples from two quarries	4.88	3.54	4.14
Trap: two samples from one quarry	3.03	2.07	2.55
Quartzite: two samples from one quarry	2.70	2.28	2.49
Limestone: fourteen samples from seven quarries	2.22	0.79	1.51

[1] For description of this machine see the Report of the Massachusetts Highway Commission for 1899, pp. 59, 60.

SPECIFIC GRAVITY

The weight of a rock per cubic foot will increase with the specific gravity proper and decrease with the percentage of pore space. As indicated in a previous paper, the average specific gravity of the mineral constituents is taken as the specific gravity proper of the rock. Following this conception the pore spaces are not considered a part of the rock mass.

Twenty-five determinations of specific gravity were made on samples of granite from fourteen different quarries. The maximum specific gravity obtained was 2.713 and the minimum 2.629, while the average of all determinations was 2.655. Tests on twenty-two samples of limestone from eleven different quarries gave an average specific gravity of 2.806. The maximum specific gravity was 2.856 and the minimum 2.700. Tests on thirty-two samples of sandstone from sixteen different quarries gave an average specific gravity of 2.618. The maximum specific gravity was 2.660 and the minimum 2.524.[1]

In the case of the sandstone it is to be observed that the iron oxide which constitutes a part of the cement of the brown sandstone is not present in sufficient quantity to appreciably affect the specific gravity. The specific gravity of the granite, however, is influenced appreciably by the abundance of the ferro-magnesium minerals, as exemplified in the case of the Athelstane granite from Amberg, which gave the highest specific gravity test. An admixture of quartzose material naturally lowers the specific gravity of limestone.

The stone which gave the highest specific gravity was a very compact and finely crystalline dolomite, and it is interesting to note that samples from this same quarry gave the highest crushing and transverse strength of any of the limestone or dolomite tested.

WEIGHT PER CUBIC FOOT

Determinations of the weight per cubic foot were made for twenty-five samples of granite from fourteen different quarries.

[1] It is thought that this low specific gravity is due to an unknown error in manipulation.

The average weight per cubic foot according to these determinations was 163.29 pounds. All of the granites tested weighed within five pounds per cubic foot of one another.

The average weight of twenty-two limestone samples from eleven different quarries was 166.70 pounds per cubic foot. The maximum weight was 176.69 pounds per cubic foot and the minimum 148.50 pounds per cubic foot. The average weight of thirty-two samples of sandstone from sixteen different quarries was 136.36 pounds per cubic foot. The maximum weight was 153.63 pounds per cubic foot and the minimum 115.55 pounds per cubic foot.

POROSITY AND RATIO OF ABSORPTION

As has been previously pointed out, the porosity gives the volume relation between the pores and the mass of the stone, while the ratio of absorption gives the weight relation. None of the granites tested had a porosity of more than 1 per cent., while the porosity of most of the samples was about .45 of 1 per cent. Owing to the interlocking character of the grains, the pores of a granite are much smaller than those of arenaceous limestone or sandstone. The water is therefore taken up and given off very slowly. The ratio of absorption of the granite samples tested was nearly the same as the porosity.

The limestone samples gave porosities ranging from 13.36 per cent. to .14 of 1 per cent. The sample having a porosity of 13.36 per cent. had a ratio of absorption of about 5.6 per cent. The samples from the Marblehead Lime and Stone Company's quarry, which gave the high crushing and transverse strength tests, had a porosity of about .70 of 1 per cent.

The porosity of the sandstone samples ranged from 4.81 per cent. to 28.28 per cent. The average porosity of the brown sandstone samples was between 19 and 20 per cent. In the case of the samples of sandstone having a porosity of 28.28 per cent. the ratio of absorption was 15.22 per cent. The Lake Superior brown sandstones gave an average ratio of absorption of less than 10 per cent.

The walls of a building constructed out of a porous stone are seldom completely saturated with water, although they may be wetted by the water of imbibition which adheres as a film to the individual grains and is thus conducted through the body of the wall. If a stone with pores of capillary size should be saturated in any part with water and the supply be discontinued the interstatial water would be very quickly drawn off at the surface or at the base of the wall through capillarity. It rarely happens that atmospheric conditions are such that a stone with capillary pores can become saturated with water and freeze before the water is sufficiently dissipated to prevent injury.

Rocks in which the grains are closely compacted, without respect to size, will have a small percentage of pore space and also pores of very small size. Many of the pore spaces of the granite and limestone are certainly of not greater than sub-capillary size. Water is taken up and given off by a rock having pores of this size much more slowly than by one in which the pores are of capillary dimensions. When the sub-capillary pores of a rock contain water in any quantity they should be theoretically filled. The sub-capillary pores near the exposed surface of a stone wall may be filled by long-continued rains, although the water may never penetrate to any considerable depth. If such a period of weather is followed by freezing conditions a stone in which the pores are of sub-capillary size will be in greater danger than one having pores of capillary size. It should be remembered that stone is damaged by freezing only when the pores are over nine tenths filled with water.

A wall built out of granite or other stone in which the porosity may be very low, but the pores of sub-capillary size, is in as great danger from alternate freezing and thawing as a wall built out of sandstone or other rock in which the porosity is 15 or 18 per cent., but in which the pores are of capillary size. It must be understood that this does not apply to laminated, bedded, or shaly stone, between the layers of which the water may collect more rapidly than it can be carried off through the pores. Water which is thus collected along bedding or other parting

planes cannot be considered under the head of interstatial water, although it is a very prominent cause for the disintegration of building stone.

TABLE V

	Specific gravity	Porosity	Ratio of absorption	Weight per cubic foot
Granite:				
Maximum	2.713	.55	.500	169.05
Minimum	2.629	.019	.04	163.29
Average	2.655	.329	.158	164.98
Limestone:				
Maximum	2.856	13.36	5.60	176.69
Minimum	2.700	.53	.19	148.50
Average	2.806	4.89	1.946	166.70
Sandstone:				
Maximum	2.660	28.28	15.22	153.63
Minimum	2.524	4.81	2.00	115.55
Average	2.622	15.89	7.486	136.36

FREEZING AND THAWING TESTS

As said in a previous paper, the difficulties involved in manipulation and the many conditions which must be considered before conclusions can be drawn from quantitative results of freezing and thawing tests, have apparently had the effect of almost excluding these determinations from reports on building stones. The effect of alternate freezing and thawing may be manifested in three ways: (1) cracks may form; (2) small particles or grains may be thrown off from the surface, occasioning a loss in weight; (3) the cement may be weakened or the grains broken, causing the strength to be materially lessened.

Cracks.—Cracking, as a result of freezing, is seldom observed in the laboratory tests, owing to the careful manner in which the samples are usually prepared.

Loss in weight.—Small particles are frequently shoved off from the surface of a sample which is subjected to alternate freezing and thawing. Where incipient joints occur small flakes are also sometimes loosened by pressure of the freezing water. Many of the grains at or near the surface of sandstone samples become loosened in the process of sawing or hammer dressing. These grains usually adhere to the sample so loosely that they

fall away from the parent mass under very moderate pressure. Loose particles at the surface are naturally more plentiful in the case of sedimentary rocks such as sandstone than they are in the case of igneous rocks or finely crystalline limestone. The loss in weight due to alternate freezing and thawing *will depend mainly* upon the manner in which the samples have been dressed and the kind of stone tested. The experiments which I have performed have demonstrated to my satisfaction that alternate freezing and thawing for a period of thirty-five days results in scarcely more than the removal of the loosened grains or fragments from the surface. Any loss in weight which may be partly accounted for by the manner of preparing the samples does not indicate the extent to which the stone has been injured.

Loss in weight due to freezing and thawing was determined for eighteen samples of granite from eleven different quarries. The loss in weight in these cases did not exceed .05 of 1 per cent. on a mass of about 350 to 360 grams. In the case of limestone, in which twenty-one samples from eleven different quarries were tested, the loss did not exceed .3 of 1 per cent., being, as a rule, less than .1 of 1 per cent. The loss in weight of the sandstone samples, of which twenty-four from twelve different quarries were tested, did not exceed .62 of 1 per cent. and averaged about .28 of 1 per cent.

TABLE VI

FREEZING AND THAWING TESTS

Loss per cent. of weight

	Highest test	Lowest test	Average
Granite and rhyolite: sixteen samples from eleven different quarries....................	.05	.006	.035
Limestone: twenty-one samples from eleven different quarries.........................	.30	.005	.0753
Sandstone: twenty-four samples from twelve different quarries.........................	.62	.015	.276

Such losses in weight are almost insignificant, and are valuable mainly in showing that the more loosely compacted

sandstone samples have more of the exterior grains loosened in preparation than do the granite, rhyolite, and limestone. It is very probable that had these same samples been subjected to a second period of alternate freezing and thawing, the granite, limestone, and sandstone would have agreed more nearly in the loss by weight.

Loss in crushing strength.—The result of alternate freezing and thawing is more clearly manifested by a decrease in the crushing strength of the rock than by the loss in weight. It is very evident that if a stone having sub-capillary pores is subjected to alternate freezing and thawing for a considerable period, the adhesion of the particles will be weakened and the cement perhaps shattered or broken. This will not necessarily occasion an immediate loss in weight, but must necessarily decrease the strength of the stone. The samples which were subjected to alternate freezing and thawing for thirty-five days were broken in a testing machine to determine their crushing strength. The crushing strength thus obtained was compared with the crushing strength obtained from the samples of fresh stone. With a few explainable exceptions, the crushing strength of the frozen samples of granite was much less than that of the fresh. The crushing strength of the frozen samples from ten different granite quarries was less than the crushing strength of the fresh samples by from 2201 pounds to 13,075 pounds per square inch. In the case of limestone samples from eleven different quarries the frozen samples from eight showed a loss in crushing strength of from 571 pounds to 18,714 pounds per square inch. Among the frozen samples of sandstone from ten different quarries, six gave crushing strength tests which ranged from 326 to 6264 pounds per square inch lower than the crushing strength of the fresh samples. The average loss for all the frozen samples of each kind of rock is given in Table VII. Table VIII gives a comparison between the average crushing strength of fresh and frozen samples, and also the average loss through freezing.

TABLE VII

ULTIMATE STRENGTH IN POUNDS PER SQUARE INCH OF FROZEN SAMPLES

	Highest test	Lowest test	Average
Granite and rhyolite: sixteen samples from twelve different quarries....................	37,027	9,765	22,875
Limestone: twenty-one samples from eleven different quarries.........................	34,784	5,584	18,267
Sandstone: twenty-four samples from twelve different quarries...........	9,245	2,116	4,724

TABLE VIII

COMPARATIVE CRUSHING STRENGTH OF FRESH AND FROZEN SAMPLES

	Crushing strength of fresh samples	Crushing strength of frozen samples	Difference, or loss in strength through freezing
Granite and rhyolite: average difference in strength of twenty-three fresh and eighteen frozen samples from eleven different quarries	29,696	22,793	6,903
Limestone: average difference in strength of twenty-one fresh and twenty-one frozen samples from eleven different quarries..........	25,222	18,267	6,955
Sandstone: average difference in strength of eighteen fresh and twenty-four frozen samples from ten different quarries.................	5,461	4,453	1,008

These experiments illustrate two points which I have made in the previous discussion: (1) that the results of freezing and thawing can be best estimated from the loss in crushing strength; (2) that the larger the pores, without respect to the percentage of pore space, the less will be the injury from freezing and thawing. There is little doubt but that a stone having a high percentage of pore space, *if completely saturated* with water and frozen, will suffer greater injury than one with a lower percentage. But the conditions under which freezing takes place must be considered before conclusions reached are of any practical value. These conditions include a time element which enters to modify very materially the results. After making this time element as short as the conditions under which the experiments

were performed would permit, it was demonstrated that the strength of the sandstone, which had a high percentage of pore space, was less affected by freezing and thawing than the strong granites and limestones having a low percentage of pore space. It was naturally thought that the Dunnville sandstone, which has 28.28 per cent. of pore space, and consists of relatively fine particles, would experience a greater loss in strength than any of the other rocks tested. The results, however, give evidence that a rock as fine-grained and poorly-cemented as this, with pore spaces which are little greater than sub-capillary size, is but slightly injured by alternate freezing and thawing.

It has been a matter of frequent observation that limestone and marble suffer more by hard freezing immediately after being taken from the quarry than other stones which have a higher porosity. This has usually been spoken of as exceptional, but I venture to say that between limestone, marble, and sandstone, the two former can furnish more examples of injury by freezing of interstatial water than the latter. A reasonable explanation for this result would be that the pore spaces in the limestone are usually of sub-capillary size, while those in the sandstone are mainly of capillary size.

EFFECTS OF SULPHUROUS ACID GAS

Limestone, dolomite, and marble are the only stones which are to any extent injured by sulphurous acid gas. Eleven samples of limestone and dolomite from as many different quarries were exposed for forty-four days to sulphurous acid gas in a moist atmosphere. Some of the pieces of limestone were colored yellow, others were slightly etched on the surface, while many of the samples showed a glistening precipitate of magnesium salts. By washing the samples the magnesium salt was taken into solution and through this the weight of the sample was slightly decreased.

The deterioration of limestone or dolomite in a moist atmosphere laden with sulphurous acid gas is apparently not very rapid. Where deterioration does not proceed very rapidly under

such extreme conditions, in an ordinary atmosphere it would be many years before the gas would have any appreciable effect upon the limestone in the walls of a building.

EFFECT OF CARBONIC ACID GAS

Eleven samples of limestone and dolomite were tested to determine the effects of carbonic acid gas in a moist atmosphere. After treatment for forty-four days there was apparently no deterioration either in weight or color.

EFFECT OF HIGH TEMPERATURE

Few experiments have thus far been performed to determine the limit of temperature which different kinds of stone will stand without injury.[1] It is known, however, that a stone will stand a much higher temperature when heated and cooled slowly than when heated and cooled rapidly.

Samples of granite from six different quarries were tested in a muffle furnace to determine the temperature which they would stand without being destroyed. The samples were all practically uninjured up to a temperature of 1200° F. but most of them were destroyed before a temperature of 1500° F. was reached. Eleven different samples of limestone from as many different quarries were tested and each of them was partially calcined before a temperature of 1400° F. was reached. The eleven samples of sandstone which were tested were mostly destroyed at a temperature of less than 1200° F. although in one instance a temperature of 1500° F. apparently left the sample uninjured.

All the heated samples when struck with a hammer or scratched with a nail emitted a sound very similar to that given off by brick. Planes of lamination were brought out more distinctly as the temperature increased.

The samples of granite cracked differently depending upon whether they were coarse or fine grained. The very coarse grained granite samples broke in a great many places and may be said to have exploded. The cracks were so numerous in one

[1] See "Notes on Building Stones" by HIRAM CUTTING, Montpelier, Vt., 1880.

EXPLANATION OF PLATE I

RESULTS OF CRUSHING GRANITE AND RHYOLITE

The figures in this plate illustrate some of the more perfect cones resulting from crushing the stronger samples of granite and rhyolite. Fig. 1 is a typical result for granite of this class, while Fig. 3 is a typical rhyolite cone. This latter cone resulted from crushing a two-inch cube of granite, which gave a test of nearly 48,000 pounds per square inch. It will be further observed that Figs. 4 and 5 have wedge-shaped apices similar to those illustrated in Pl. IV, Fig. 3.

Jour. Geol., Vol. VIII, No. 6 Plate I

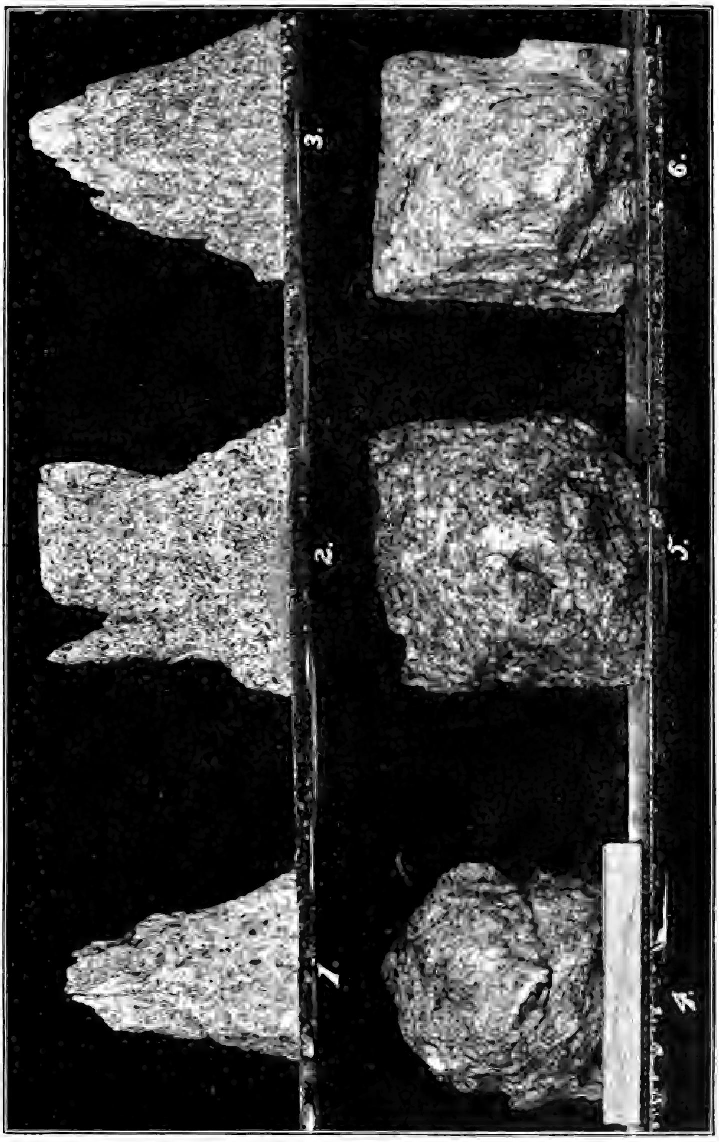
Results of crushing granite and rhyolite cubes.

EXPLANATION OF PLATE II

Figs. 1, 2, and 3.—These samples illustrate the different forms developed in crushing granite cubes. The one on the left is a typical cone. The one on the right has a tendency toward the wedge-shaped form, while the one in the middle is a typical wedge form. The upper part of this wedge is a sharp ridge from one end to the other.

Figs. 4, 5, and 6.—These three figures have their apices pointing toward the observer. They are all well shaped cones, in which there has been especially well developed the concentric structure referred to in the text.

JOUR. GEOL., VOL. VIII, No. 6 Plate II

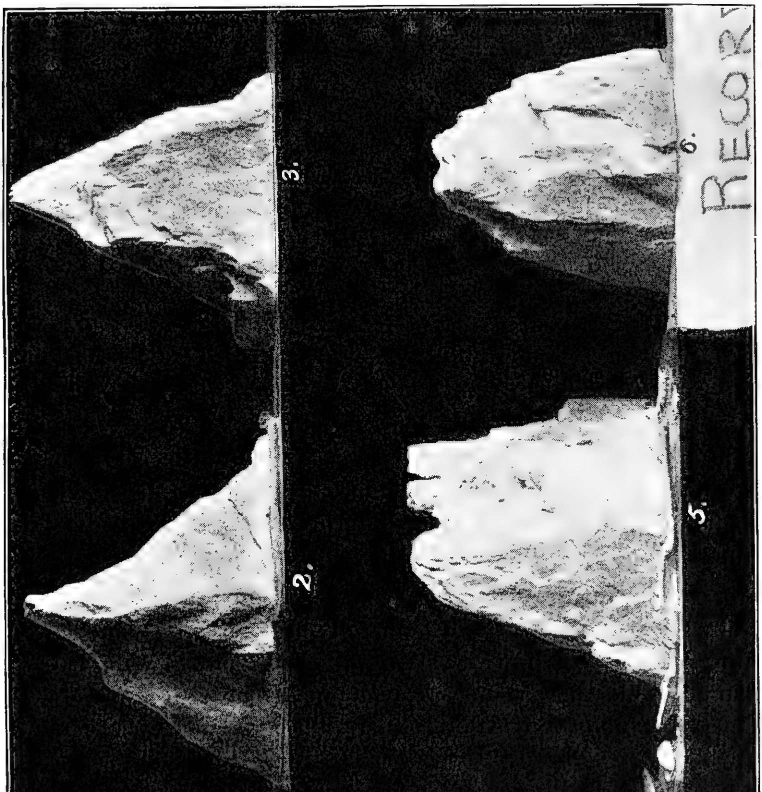


Results of crushing granite cubes.

EXPLANATION OF PLATE III

The figures in this plate illustrate the results of crushing samples of the strongest limestone of Wisconsin. The sample in the lower right hand corner, Fig. 6, gave a crushing strength test of 42,787 pounds per square inch, which is thought to be the highest record obtained for any limestone, dolomite, or marble quarried in the United States. This sample shows, near the apex of the somewhat irregular cone, the concentric cleavage structure, which is typically developed in the granite.

Jour. Geol., Vol. VIII, No. 6 Plate III



Results of crushing limestone cubes.

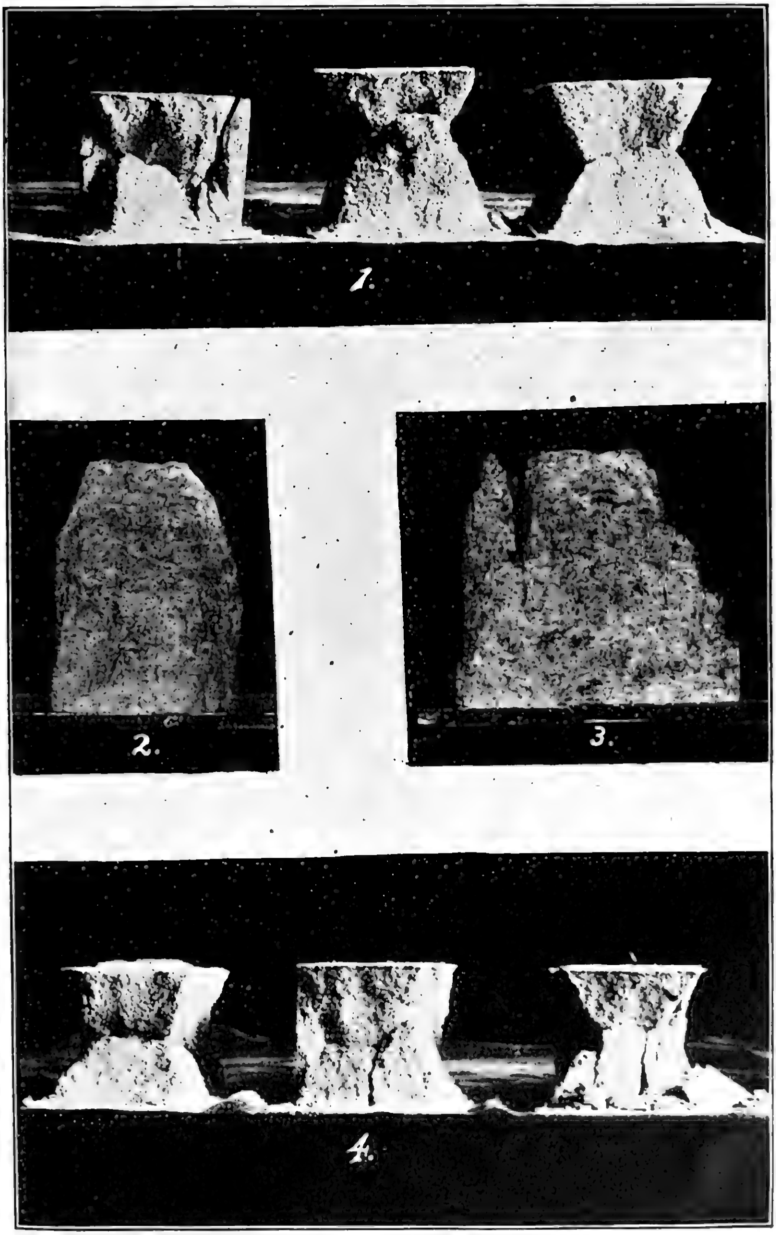
EXPLANATION OF PLATE IV

FIG. 1.—Samples of brown sandstone in which the pyramidal forms are well developed.

FIGS. 2 and 3.—Samples of granite. Only the upper wedge or pyramid was developed in each cube. Fig. 2 approaches the conical form, which ordinarily results from crushing granite. (See Pl. II.) Fig. 3 is the typical wedge-shaped form, which often results from crushing granite of medium strength.

FIG. 4.—Samples of brown sandstone in which the pyramidal structure is well developed. These are typical results obtained from crushing sandstone of ordinary strength. It should be observed that the samples which have a low or medium crushing strength are the only ones in which two equally well developed pyramids occur.

Jour. Geol., Vol. VIII, No. 6 Plate IV



Results of crushing sandstone and granite cubes.

EXPLANATION OF PLATE V

The samples numbered 1, 3, 6, 7, 13, and 16 are granite; those numbered 8, 9, 10, and 11 are limestone; and numbers 2, 3, 4, 12, 14, and 15 are sandstone. Samples numbered 5, 6, and 13 were cooled suddenly by immersing them in cold water, while the remaining were cooled gradually. Number 6 is fine grained, number 5 medium grained, and number 13 coarse grained granite. It is simply necessary to direct attention to these samples, for one to see how the difference in grain influenced the manner of cracking.

The limestone samples were partly calcinated. Where the quicklime has been removed the samples have the rounded edges noticed in numbers 9 and 10.

The sandstone samples are, to all outward appearances, uninjured, as shown in samples numbered 2 and 15. The chipping of the corners and edges in numbers 4, 12, and 14 was occasioned by pressing the thumb against the parts broken off, which in spite of the uninjured appearance of the samples, indicates the friable character of the stone after heating to the extreme temperature of 1300°–1500° F.

JOUR. GEOL., VOL. VIII, No. 6 Plate V

Results of subjecting different kinds of stone to high temperatures.

EXPLANATION OF PLATE VI

FIG. 1.—A sample of medium-grained granite heated to a temperature of from 1300°–1500° F., and suddenly cooled by immersing in cold water. This figure is a good illustration of the result of throwing a stream of water on the walls of a burning building, which is con structed out of granite of this texture.

FIG. 2—The sample in the upper left hand corner is sandstone which has become so friable by being heated to a temperature of 1300°–1500° F., that it crumbles when pressed between the fingers. The remaining samples are limestone. They have flaked off at the corners, due to having been quickly cooled from a very high temperature. Such results may frequently be noticed in the limestone walls of buildings which have been destroyed by fire.

JOUR. GEOL., VOL. VIII, NO. 6 Plate VI

Results of rapidly cooling samples of granite, limestone, and sandstone that have been heated to a high temperature.

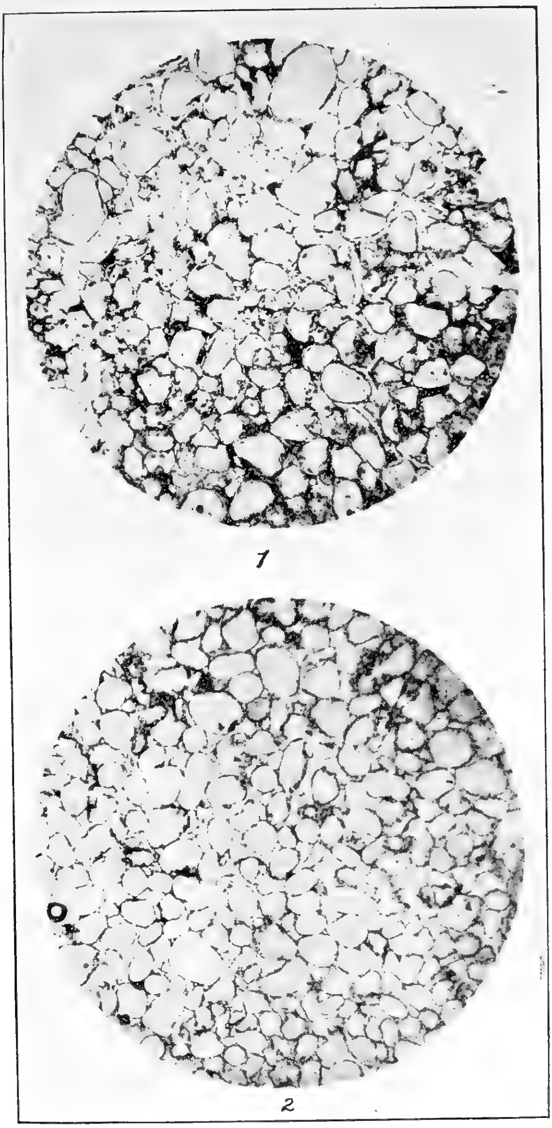
EXPLANATION OF PLATE VII

FIG. 1.—Section No. 4721. (× 12.)[1] Red sandstone from LaValle. This is an excellent illustration of a sandstone in which the grains were originally uniformly well rounded, and later enlarged and cemented with silica. The enlargements are nicely shown in many places in the section. The brown rims of iron oxide which separate the original grains from the secondary quartz are very distinct in the figure.

FIG. 2.—Section No. 4720. (× 12.) Brown sandstone from Argyle. This section illustrates a rock in which the grains are well-rounded and cemented with iron oxide, but in which the individuals have not been generally enlarged with secondary quartz. On account of this the stone is considerably weaker than the one from LaValle.

[1] Magnified twelve diameters.

Jour. Geol., Vol. VIII, No. 6 Plate VII



Thin sections of sandstone.

EXPLANATION OF PLATE VIII

FIG. 1.—Section 4719 (× 12). Lake Superior brown sandstone from the Chequamegon Area. This section is composed mainly of quartz and the accompanying figure shows the size, shape and arrangement of the grains. It will be observed that they do not interlock.

FIG. 2.—Section 4714 (× 12). Lake Superior brown sandstone from the Chequamegon Area. The grains are somewhat better rounded in this, than in the preceding section. One will quickly notice the secondary quartz which in many places cements the individual grains together. Occasional grains of feldspar occur among those of quartz.

Jour. Geol., Vol. VIII, No. 6 Plate VIII

Thin sections of sandstone.

EXPLANATION OF PLATE IX

FIG. 1.—Section No. 4736. (× 12.) Dolomitic limestone from Duck Creek. This figure is an excellent illustration of the way in which the individuals of the coarser crystalline limestones interlock.

FIG. 2.—Section No. 4726. (× 12.) Dolomitic limestone from Sturgeon Bay. This figure shows the close, compact character of the crystalline dolomites, which accounts for their low percentage of pore space, and partly for their high crushing strength.

JOUR. GEOL., VOL. VIII, No. 6 Plate IX

Thin sections of limestone.

EXPLANATION OF PLATE X

FIG. 1.—Section No. 4733. (× 12.) Berlin rhyolite. This figure shows the exceedingly fine grained matrix and the porphyritic individuals of feldspar, which are characteristic of the rock in the hand specimen. The mica which occurs in small flakes is also nicely shown. The parallel arrangement of the small flakes, which is evidently a cause for the "rift" in the rock, is well brought out. The cracking of the feldspar, referred to in the text, is also seen in this figure.

FIG. 2.—Section No. 4704. (× 12.) Utley rhyolite. Porphyritic crystals of quartz and feldspar and a small portion of the fine, dense matrix are shown in this figure. The compactness of the rock, with the consequently minute pores and low porosity are very evident.

JOUR. GEOL., VOL. VIII, NO. 6 Plate X

Thin sections of rhyolite.

EXPLANATION OF PLATE XI

FIG. 1.—Section No. 4702 (× 12). Granite from Waupaca. This rock contains a greater variety of minerals than No. 4711. Besides quartz and feldspar there is an abundance of chlorite, epidote, and, in some places, biotite. The individuals are interlocking, but less regular than in many granites.

FIG. 2.—Section No. 4711 (× 12). Granite from Granite Heights. The dark colored parts are feldspar, and the lighter colored are quartz. This section illustrates nicely the close, interlocking character of the different individuals which contributes largely to the strength of the rock.

JOUR. GEOL., VOL. VIII, NO. 6 Plate XI

Thin sections of granite.

of the samples that it broke into fragments not much larger than the individual grains. The granites having medium sized grains flaked off at the corners when cooled moderately fast. The fine grained granite, such as the Montello, developed cracks through the middle of the sample. The different ways in which the granites were cracked and broken are illustrated in Plate V.

In contrast with the limestone and granite, the sandstone was to all appearances little injured by the extreme heat. Samples which were taken from the muffle furnace and allowed to cool gradually appeared to be uninjured, but after they had cooled one could crumble any of them in the hand almost as easily as he could the most incoherent sandstone. In fact, some of the samples when heated to a temperature of 1500° F. became so incoherent that after they had cooled they could scarcely be picked up without falling into sand. A person might be easily deceived as to the injury occasioned by extreme heat on sandstone. The samples often look as fresh and clean as when first quarried and, unless tested with the hammer, one would never suspect that the strength was so largely gone.

In general, the temperature tests indicate that there are few if any stones, whether they be granite, limestone, or sandstone, which will effectually withstand for a moderate length of time a temperature of 1500° F.

MICROSCOPIC TESTS

Thin sections of the more important building stones which were otherwise inspected were examined under a compound microscope. The microscopic examination reveals clearly the texture, composition and finer structures of the rock. These, combined with the field observations, furnish abundant data from which a person familiar with microscopical studies can estimate both the strength and durability of a stone.

The irregular interlocking character of the grains composing the igneous and finely crystalline rocks give evidence of strength which far exceeds that displayed by the sandstones composed of rounded grains which are held together by occasional patches of

ferruginous or siliceous cement. Each sample by itself has peculiarities in texture and composition which either add or detract from the strength and durability of the stone.

Plates VII, VIII, IX, X, and XI, with the accompanying explanations, illustrate the character of several of the Wisconsin building stones and the elements which contribute to their strength and durability.

E. R. Buckley.

Reviews

Glacial Erosion in France, Switzerland, and Norway. By WILLIAM MORRIS DAVIS. Proc. Bos. Soc. Nat. Hist., July 1900; 49 pp., 7 figures, 3 plates.

In this admirable essay Professor Davis gives cogent reasons for modifying his former views relative to the efficiency of glaciers as erosive agents. A gradual change from a former conservative opinion which had been in progress in recent years was greatly accelerated by his studies in the Alps, Norway, and France during the past year. These studies lay along those topographical lines which Professor Davis had cultivated for the past two decades with such eminent success. They centered on the great discordance which he observed between the main and the tributary valleys when the former have been occupied by ice streams and the latter have not, or at least have not been effectively modified by glaciers. The tributaries in such cases have been styled by Gilbert "hanging valleys" because, instead of joining their primaries on well-adjusted normal gradients, they enter high up on the side walls. The tributary streams cascade down an abrupt declivity in entering the main glaciated valley in a manner quite out of harmony with their normal behavior within the tributary valleys above or in the glacial valleys below. Associated with the topographic break between the tributaries and the glacially worn primaries there are contrasted physiographies that point, as it seems to the author, and to the reviewer as well, unequivocally to the origin of the phenomena. In the tributary valleys, although in Pleistocene times they were involved in the general glaciation of the region, in some measure at least, the characteristic configuration of weathering and of water erosion clearly predominates, while in the main valleys, which have been the chief channels of glacial movement, flat bottoms and precipitous sides, bearing the peculiar aspects of glacially worn troughs, prevail. No observant traveler in Switzerland has failed to note the numerous small streams that cascade down the abrupt walls of the glaciated valleys. The numerous falls of Aar Valley, especially

that portion immediately below the Unter-Aar glacier, is a familiar and striking example.

Although these phenomena have long been noticed and some appreciation of their signification has been felt, it remained for a master in modern physiography to see and to set forth their fuller meaning. It is assumed that in the pre-glacial times the tributaries joined the trunk streams in the normal way with well-adjusted gradients, and that the discordance now shown is the result of the superior erosion of the trunk valleys by the glacial tongues that occupied them. The amount of the discordance is, therefore, taken as a rough measure of the superior erosive efficiency of the glaciers. In the Alps this is recorded in hundreds of feet, and in Norway it reaches into the lower thousands, and gives an impressive illustration of the erosive power of glaciers.

There are, however, several qualifications to be applied to this rough measure, and these are rather more complicated, and perhaps more important, than one might apprehend from reading the paper, though they do not seriously affect its method or its conclusions. In the broadening of the main valley by glacial erosion the mouths of the tributaries were cut back and the present points of intersection lie at higher levels than the original axis of the main valley. This is theoretically restored by projecting the gradient lines of the tributaries till they meet in the center of the main valley. For the main purposes of a general view, such as is sought by the paper, it is, doubtless, sufficiently near the truth to project the present lines of the tributary valleys without modification, but in stricter studies it is necessary to recognize the changes which the tributary valleys have undergone while the main valleys were being deepened by glacial erosion.

If unobstructed erosion was in progress in the tributary valleys while the main ones were being excavated by glaciers, the discordance between the two at the close would measure the *difference* in the rates of erosion of glaciers and of ordinary agencies, and a plus correction would be necessary to secure the absolute glacial erosion. During a part of the glacial period the tributary valleys were smothered in a general mantle of ice and suffered glacial modification as well as the main valleys, but not in just the same way. The main valleys lay in the chief direction of ice movement, for they determined it. The tributaries in the main lay more or less athwart the ice movement. They must hence be presumed to have suffered more or less of rasping

down of their rims and of filling up of their axes, and they thus assumed lower reliefs and flatter lines. The projection of their lines thus modified would not accurately represent the true preglacial lines. If the general glaciation sustained a large ratio, dynamically speaking, to the local or valley glaciation, this modification might introduce an error of some moment. As a matter of fact, however, judging from what we know of the general glaciation of the Alps, it probably was not very material. It is less easy to say what may be true of Norway, where general glaciation was much more important both actually and relatively.

In the advancing and retreatal stages of the several glaciations another group of influences came into play. The main valleys were filled by glacial tongues which more or less effectually blocked up the mouths of the tributaries, checked erosion in them, and induced filling, as may be seen in many such valleys today in the Alps, in Greenland, and elsewhere. The valley occupied by the Märjelen See may be cited as a familiar and striking example. While the mouths of the tributary valleys were thus blocked up, their rims were being degraded and a change was thus being wrought in their configuration. The effect of this class of action was to give the tributary valleys not only gentler declivities than they had preglacially, but gentler even than they would have acquired in the natural degradation of the basin had it remained open and free from ice throughout. The result may be styled a premature maturity, for it was not strictly normal to valleys at such positions in the general drainage system. It was a maturity of a local nature hastened by the establishment of a transient base-level at the mouths of the tributaries by the obstructing ice.

This special phase of the reshaping of the tributary valleys, being of the erosive type and being aided by the special climatic conditions of the time and by the high declivities of the valley sides, doubtless quite rapidly removed the signs of the previous subduing effects of general glaciation and restored an aspect resembling the preglacial one without being such, and hence made it difficult to distinguish this pseudo-maturity, if it may be so called, from such degree of maturity as had been attained in preglacial times, or, if you please, such an ideal stage of maturity as would have been reached by subærial erosion had not glaciation interfered. A restoration of the preglacial conditions of the main valley based on the lines of this pseudo-maturity of the tributaries would obviously involve error. Its amount depends on

the value of these phases of action, and that in turn is dependent on the duration and complexity of the glacial period.

A strict discussion is constantly vexed by the question whether the competency of the glaciers to erode is to be measured by the absolute amount of work done by them during their existence, be it longer or shorter, or by the ratio of the work they do to that which would be done by the usual erosive agencies in the same area and for the same time. Are we trying to determine the absolute or the relative? The latter is probably the truer basis of estimation in general, but both have their special values.

In the case in hand, such degradation of the tributaries at their mouths as took place during the period of glaciation lowered the base of reference by which the glacial erosion is measured, and a plus correction is required to give its absolute amount as already indicated. The lowering of the gradients and the premature flattening of the tributary basins, if uncorrected, leads to an erroneous projection of lines across the valleys and requires a negative correction in absolute measurement, and a more complicated and serious correction in relative measurement.

These suggestions do not cover the whole case, but they go as far as is perhaps permissible in a review, indeed, not unlikely farther than is warranted in the review of a paper based on fugitive studies that do not claim an exhaustive character. The importance, or otherwise, of the qualifications suggested depends much upon the duration and the fluctuations of the glacial period and the ratio of the general glacial action to the local valley phases.

If there is any reference in the paper to similar discordances between main valleys and tributaries not in any way connected with glacial erosion, it escaped the eye of the reviewer. Such cases of declared form exist and might naturally be expected to find at least passing recognition in a paper founded on discrepancies of this kind, the more so because in this neglected class also the main valleys are discrepantly broad and deep and the tributaries cascade down into them not unlike those described in the paper, though much less strikingly. Probably the neglected case has little application to the Alpine valleys discussed, and perhaps only an unimportant application to those of Norway. The case referred to arises from changes of drainage, whereby large volumes of water are thrown into valleys that had previously carried much less; such cases, for example, as the Upper

Ohio and the Upper Missouri. In these cases the great accessions of water have broadened and deepened the main channels out of all concordance with their tributaries. These at some distance back from the trunk streams run in their old valleys slightly modified, but as they approach the main valley, they rush down through new gorges, not, indeed, as steep and picturesque as those of the Alps or of Norway, but of like type. These have for some time been distinctly recognized, and are in constant use as working criteria in discriminating earlier and later systems of erosion, involving changed conditions. (See "Further Studies of the Drainage Features of the Upper Ohio Basin," Am. Jour., Sec. XLVII, April 1894, pp. 261–262.)

It seems to have been demonstrated that in Norway the glacial summit was some distance east of the present topographic divide and that hence the Norwegian valleys were called upon to carry away an amount of drainage greater than that which normally belonged to them in preglacial times. This took the form of ice at certain stages, and of water issuing from the edge of the ice field at other stages. How far this may have contributed to the observed result it is hard to guess without knowing more of the detailed history of the glacial period in that region, but it illustrates the connection of this mode of origin of discrepancies between trunk streams and tributaries with similar discrepancies of a true glacial origin. It is probable that even in the Alps, partly by topographic modification and partly by superior condensation, glaciation has concentrated an exceptional amount of drainage in the trunk valleys.

It is not probable, however, that any or all of the modifications herein suggested, or any others, seriously affect the representative truthfulness of the rough estimate of the superior erosive power of glaciers founded on discordance between the tributary hanging valleys and the glaciated trunk valleys. The paper is a valuable contribution to the doctrine of glacial erosion, and is likely to be the more influential with those holding opposite views because it comes from one who has heretofore held a conservative position on the subject.

The reviewer does not, on first reading, sympathize fully with the effort of Professor Davis to extend the analogy of river erosion so unreservedly to glacial work as done in the paper. The analogy is truer in gross externals than in refined analysis. A river erodes by virtue of its pressure and momentum, scarcely at all by rigidity. Very largely its work is done by the striking force of particles driven rapidly

against the valley walls and bottom, or against each other. This is largely true even of the pebbles rolled on its bottom, as anyone may see by examining the nick-marks that cover their surfaces and that sharply distinguish them from glaciated pebbles, or by critically comparing a waterworked surface with a glacially worn surface.

On the other hand a glacier does its work by virtue of its rigidity and pressure, and scarcely at all by its momentum, for its velocity is very low. A river with the same velocity as a glacier would be almost absolutely inert as an abrading agency. In the judgment of the reviewer no one is entitled in the present state of evidence to assume that the laws of fluids control the action of glaciers except in external similitude, which is due to the fact that gravitation is the dominant factor in both cases. In convenient and popular exposition the similitude has many advantages, but in framing scientific doctrine and nomenclature, and still more in mental procedure, it is attended by danger. It is doubtless as important to avoid the similitude in critical work as it is permissible to use it in easy exposition.

T. C. C.

Bartholomew's Physical Atlas: An Atlas of Meteorology. Vol. III. A series of over four hundred maps. Prepared by J. G. Bartholomew, F.R.S.E., and A. J. Herbertson, Ph.D., and edited by Alexander Buchan, F.R.S. Under the patronage of the Royal Geographical Society. Edinburgh, 1899.

This is the first volume to appear of what promises to be an epoch making work in scientific geography. The entire field of physical geography is to be covered by seven volumes. The plan was furnisht by the famous *Physikalischer Atlas* of Berghaus, tho the field is vastly extended, and it will make a work when completed, perhaps ten times the size of the German atlas.

This great venture is preparing under the direction of J. G. Bartholomew, revised and edited by a corps of eminent specialists, in volumes as follows:

I. Geology — Sir Archibald Geikie.
II. Oceanography — Sir John Murray; and
Orography — Professor James Geikie.
III. Meteorology — Alexander Buchan,
IV. Botany — Professor Bayley Balfour.

V. Zoölogy — P. L. Sclater.
VI. Ethnography — Professor A. H. Keane ; and
Demography — Professor Elisee Reclus.
VII. Cosmography — Professor Ralph Copeland ; and
Magnetism — Professor C. G. Nott.

It is now about half a century since the appearance of a great English work along these lines, that of Dr. Keith Johnston, based on the *Physikalischer Atlas* of Dr. Heinrich Berghaus (1837–1852). The original German publication is justly regarded as a landmark in the history of geography, and has been kept at the forefront of high art in cartography by his nephew, Dr. Hermann Berghaus, who brought to his aid some of the most famous German scholars, such as Hann, Neumayr, Zittel, and others. This is the work which has been such an inspiration to the students of geology and geography in the present generation, and this atlas it is which has furnisht the plan for the greater Scotch work now in preparation. To quote from the prospectus:

Recent years have marked a great and rapid development in the field of scientific geography. The additions to our previous knowledge have been numerous and important, but they are scattered throughout hundreds of publications, in various languages, they are difficult to find, and known only to specialists in each department. Hence there is a need for a work embodying in concrete and graphic form a digest of all this scattered material — a new physical atlas.

So some years ago the enterprising Scotch firm obtained copyright privileges on the material in the Berghaus plates, and planned at much larger work, one of over two hundred plates, compiled from sources liable to be of more immediate interest to English and American students, getting the heartiest coöperation from the world's greatest specialists along all the desirable lines; ten years have already gone to the preparation of the most comprehensive work of the kind ever attempted. The cost of production alone will reach a half million dollars.

Curiously enough meteorology, the youngest of the physical sciences, is so far advanced in the accumulation of data from very wide areas of the earth's surface, that it is in the most forward condition of all as to the possibility of charting complete data. Mr. Alexander Buchan makes this rather startling statement :

If the present state of the science of meteorology as regards the geographical distribution of results be compared with that of the other sciences such as

geology and the biological sciences, it stands second to none. None of these sciences can show such a world-wide distribution of precise results as are collected in this atlas of meteorology, in illustration of the geographical distribution of temperature, pressure, humidity, cloud, rainfall, and movements of the atmosphere, with illustrations of their influences over, and interrelations with, each other.

Dr. Hann's *Atlas der Meteorologie* was the first attempt to chart systematically the data of the science. His atlas, as found in Berghaus, has twelve plates, giving about sixty maps. And, altho this has been brought down to 1887, there has been a very great advance in all lines of the science since then, and the time is ripe for a more complete publication. A mass of widely scattered observations from all over the world is now charted for the first time.

The 400 maps of this atlas of meteorology are groupt under the two heads of Climate and Weather. The climate maps summarize the great mass of observations, first for the whole world, next for more detailed study of regions specially rich in observational data. There are monthly and annual charts for the elements of climate—temperature, pressure, winds, cloud, sunshine, and rainfall. The weather maps show the most characteristic weather types for given periods over defined regions.

Preceding the charts there is a general introductory article, and a special discussion of each chart. This will be of the highest value to students of climate and the weather. Appendices give complete lists of all the meteorological services, with all the stations and publications. The frontispiece consists of a graphic charting of the areal distribution of observations over the earth, in which India, Europe, and the United States stand out conspicuously in their dark shading. The volume closes with a glossary of terms, and a critical bibliography, classified for all lines of research in the subject, both of which will be very helpful.

The magnitude of the undertaking of the preparation of these charts, and the accuracy we are here dealing with will be better realized when some plain statement of the figures is made. The total number of meteorological stations is, in round numbers, 380 of the Order I; 2620 of the Order II; 6600 of the Order III, and of Rainfall, 19,400; total, 29,000; special stations for crop reports will bring the grand total up to about 31,000.

The general temperature charts are based upon fifteen years' observations from 1539 stations. The general pressure charts from fifteen years' observations at 1280 stations. These reports are the summaries of about 17,000,000 observations for temperature, and about 14,000,000 for pressure, and this is excluding all observations at sea.

The charts of the first part under the general heading Climate, are classified under the headings:

I. Isotherms.
II. Isobars and wind arrows.
III. Isotherms and Isobars month to month.
IV. Isohels, the year's sunshine for Europe and North America.
V. Isonephs, distribution of cloudness over the globe.
VI. Isohyets, annual, seasonal and monthly rainfall over the globe.
VII. Maps of hyetal regions and seasonal distribution,
VIII. Isobars and Isohyets; rainfall as related to pressures.

The second part on Weather, has charts classified as:

I. Abnormally cold and hot seasons and months.
II. Pressures as related to wind in type storms.
III. Pressures as related to types of wind and weather.
IV. Storm tracks and storm frequency.
V. Type deviations from normal pressures.

The first chart in the volume shows the world's isotherms on Mercator's projection, in which the relief of the land is shown by line shadings in black. Contours of 600, 3000, 6000, and 12,000 feet are shown, and similar contours in the oceans represented by fine dotted lines. Even the little 3 × 6-inch insets show all highlands over 3000 feet by shading. This plate and No. 11, the world's isobars, are equally beautiful, and are the finest plates in the book. It will be no exaggeration to say that no more beautiful plates have ever been engraved. They are magnificent in accuracy, neatness, completeness and beauty of engraving, nor are the lesser maps less beautiful, they are merely smaller, and chart less complex data as a rule. One is struck, too, by the artistic range of coloring. The tints show with a sufficient contrast the varying values of the data charted, yet there is not a harsh note in the whole book.

Two of the most beautiful plates in the book are the charts of the monthly isotherms of the British Isles, and another of the monthly isobars and isohyets.

In all the maps the English measurements are given, and in each case their metric equivalents — the pity of it, that we need to record in two systems!

It almost seems like caviling to offer any criticism on so sumptuous a work. But there are some shortcomings. In only one case is the projection used named; it would have been an agreeable addition, had the projection been specified for all maps of lesser area, and in all such maps a horizontal scale should be given, either in arithmetical ratio, or by linear representation of miles and kilometers. There is scarcely a scale in the book.

In all maps of isohyets the very important element of altitude, it would seem, is almost a necessity for the proper interpretation of the rainfall, yet on Plate XXI, the principal plate of isohyets, there is no attempt to show altitudes, even in the larger areas of Europe and the United States. The lack of contours and the scale in such insets as Jamaica, Japan, Java, and Mauritius is a serious fault. Even in Plate XXIV in the large scale map of isobars and isohyets of the United States and Canada, only the one contour of 3000 feet is shown. Here, far more than in the general maps of Plates I and II, are the several contours needed. It may be, of course, that in some cases, for example, the India map, the relief was omitted to prevent overloading. And true it is, that with all the mass of data entered in these maps, there is never in any of them a lack of legibility.

But after all the flaws are found, they are not very serious, they are mere spots on the sun. The work will long stand as a monument to very high ability in meteorology and cartography.— J. PAUL G.

Mineral Resources of Kansas, 1899. By ERASMUS HAWORTH, Univ. Geol. Surv. of Kansas, Lawrence, May 1900; pp. 67, 4 plates.

This is the third of the annual bulletins on the mineral resources of the state which the University Geological Survey of Kansas is issuing, and is worthy of note as a laudable effort on the part of an educational institution of high grade to convey to the people, without distinction and without charge, commercially valuable information gathered under scientific auspices. Is is one of the many current indications of the breaking down of the narrow limitations that have so long hedged in the traditional institution of learning to its infinite

harm, and of the broadening and elevation of the functions of universities in the true sense of these adjectives, for an institution is broad in proportion to its contact with the full range of serious thought and with all classes of its natural constituency, and it is elevated in proportion as it is really useful, the notions of the leisure classes to the contrary notwithstanding.

The general summary shows an annual production of nearly 39 million dollars of which, however, a part appears to be the smelting and refinement of ores mined outside the state. The record shows that all the mineral industries felt the impulse of the country's general prosperity. The coal production reached a value of over five million dollars. The plaster, hydraulic cement, clay, salt, and stone industries all exhibit marked advances. Altogether it is a good showing for a state whose great industry is agriculture.

T. C. C.

Results of the Branner-Agassiz Expedition to Brazil.

I. *The Decopod and Stomatopod Crustacea.* By MARY J. RATHBUR. 23 pp., 1 plate.

II. *The Isopod Crustacea.* By HARRIET RICHARDSON, 3 pp., 4 figures.

III. *The Fishes.* By CHARLES H. GILBERT, 23 pp. 1 plate.

IV. *Two Characteristic Geologic Sections on the Northeast Coast of Brazil.* By. J. C. BRANNER, 17 pp., 5 sketch maps and sections, Proc. Wash. Acad. Sci., August 1900.

Nos. I, II, and III relate to existing forms of life, and belong to that realm of current geology which we conveniently, and doubtless wisely, leave to the zoölogists.

No. IV gives in as much detail as field circumstances would permit two sections opened by railways running from the coast toward the interior, and traversing the border formations somewhat nearly normal to their strike. The section along the Bahia and Minas Railway lies at about 18° S. Lat., and that along the Alagôas Railway between 9° 20′ and 9° 40′ S. Lat., the two sections being about a thousand kilometers apart. They show essentially the same structure : a series of relatively young sediments lapping back over old crystalline rocks. The age of the sediments is open to question, and the problem is regarded as too large for specific discussion in the paper. The evidence is thought to point to the following conclusions :

1. The Bahia basin, formerly referred to the Cretaceous, is probably either Eocene Tertiary, or Laramie.

2. The parti-colored beds along the coast, formerly referred provisionally to the Tertiary, are the same as the Bahia Eocene.

3. The sediments of the Alagôas section are of fresh-water origin, like those of Bahia.

4. No fossils have been found in the section along the Bahia and Minas Railway, but it seems probable that these beds are the southward continuation of the Bahia beds.

The crystalline series next back of the sedimentary beds consist mainly of quartz-monzonites (gabbros) granites and gneisses, the first having a notable development. The Bahia-Minas section ends in mica and other schists much faulted, wrinkled, and cut by veins, and much more deeply decomposed than the quartz-monzonites.

The contribution is doubly valuable in that it bears on the evolution of a continent that has played a peculiar and interesting part in geologic history, but which is as yet too little known to be interpreted with precision or satisfaction. The generosity of Agassiz, as well as the devotion of Branner, in securing it are to be gratefully recognized.

T. C. C.

Progress of Geological Work in Canada During 1899. By HENRY M. AMI, Can. Rec. of Sci., Vol. VIII, No. 4, July 1899.

Contrary to the natural interpretation of the title this is a list of works relating to Canadian geology published during the year 1899 through various avenues, and embracing private as well as official works. It will be found helpful to working geologists.

C.

Descriptive Catalogue of a Collection of the Economic Minerals of Canada, Paris International Exhibition, 1900.

This is somewhat more than a simple descriptive catalogue of the minerals exhibited, as it contains notes relative to the modes of their occurrence and to the industrial operations connected with them, when these are important, as well as other incidental information which gives the catalogue value as a book of reference.

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Preliminary Report on the Cape Nome Gold Region, Alaska. With maps and illustrations by F. C. Schrader and A. H. Brooks. 1900.

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Results of the Branner-Agassiz Expedition to Brazil. IV. Two Characteristic Geologic Sections on Northeast Coast of Brazil. By John C. Branner. Vol. II, pp. 185–201.

Mammals Collected by Dr. W. L. Abbott on Islands in the North China Sea. By Gerrit S. Miller, Jr. Vol. II, pp. 203–246.

THE

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DE LA COOPÉRATION INTERNATIONALE DANS LES INVESTIGATIONS GÉOLOGIQUES[1]

On a reproché à la Géologie, et ce reproche a surtout été fait par les personnes versées dans les sciences exactes, de se contenter de mesures approchées et de baser ses conclusions sur des notions parfois discutables. Il ne faut pas s'émouvoir outre mesure de cette critique ; la précision mathématique ne paraît pas conciliable en effet avec notre connaissance actuelle de la nature des choses; nous ne les pénétrons encore que d'une façon approximative, et c'est sagesse à nous, de nous garder de conclusions rigoureuses trop absolues, quand notre raisonnement ne repose que sur des prémisses insuffisamment établies.

Depuis un siècle, de louables efforts ont été tentés pour faire entrer la géologie dans la voie des sciences expérimentales, des sciences exactes. Nous devons une grande reconnaissance à James Hall qui ouvrit la voie, et à tous ceux qui l'ont suivi, et parmi eux, aujourd'hui que nous sommes en France, réunis à Paris, c'est vers Daubrée, le maître et l'ami distingué, que remontent nos pensées ; car sa place est marquée pour toujours, dans nos annales, comme celle d'un des grands pionniers de la géologie expérimentale.

[1] Presented to the eighth session of the International Geological Congress, Paris, August 1900.

Beaucoup a été fait sans aucun doute déjà pour soumettre les faits observés à des mesures précises, et pour les contrôler expérimentalement dans les laboratoires, mais il serait puéril de ne pas reconnaître qu'il reste encore beaucoup plus à faire. On peut même prévoir que c'est de ce côté que se produiront les découvertes les plus fécondes, les progrès les plus décisifs. Jusqu'ici, les efforts tentés ont été individuels, exécutés indépendamment par des savants de divers pays, marchant parallèlement dans la carrière, sans profiter, ou sans s'aider, de ceux qui travaillaient à côté. Aujourd'hui nous nous demanderons s'il ne serait pas opportun d'envisager la possibilité d'une entente, l'organisation d'une coopération internationale plus large et systématique, dans cet important domaine de recherches scientifiques? Et il nous semble que les Congrès géologiques internationaux soient naturellement indiqués pour faire aboutir pratiquement et assurer le succès d'une tentative de ce genre.

C'est une voie un peu nouvelle pour nos Congrès, mais pas complètement neuve cependant. On trouve en effet, déjà, dans leur passé, cette même tendance à une coopération méthodique des investigations géologiques; tels sont la création de notre Comité de la Carte géologique d'Europe, notre Commission des Glaciers et celle de l'Observatoire flottant. L'idée a déjà été lancée, puisque nos commissions fonctionnent; mais nous croyons qu'elle peut être généralisée et devenir d'une grande fécondité. Déjà l'an passé, à Douvres, dans mon discours présidentiel, devant la section géologique de l'Association Britannique pour l'Avancement des Sciences, et dans une occasion où les géologues anglais avaient le plaisir de recevoir un si grand nombre de leurs confrères de France et de Belgique, j'ai touché cette question, et exprimé l'espérance de la porter cette année devant le Congrès géologique international réuni à Paris. C'est ce projet que je réalise aujourd'hui, en vous soumettant les remarques qui suivent. Il m'a semblé que nulle occasion ne serait plus favorable que celle-ci, où tant de géologues, délégués de tous les points du globe, se trouvent réunis, pour parler au Congrès de son but même, et de la direction à donner à ses efforts pour développer sa bienfaisante

influence et servir la cause de la science à laquelle nous avons consacré nos vies. Le Congrès, en raison même de son caractère international, a les moyens, mieux que toute administration, d'organiser et de guider les recherches géologiques ; et on peut affirmer que s'il est possible d'aboutir pratiquement dans cette tentative de coopération et de coordination, on le devra au Congrès qui l'encouragera et la patronnera.

Dans l'état actuel de nos connaissances, nul ne peut travailler dans le vaste champ de la géologie dynamique, sans reconnaître la nécessité impérieuse et croissante d'un plus grand nombre de mesures de précision, sans souhaiter des recherches expérimentales rationnelles ; par là, cet important chapitre de la géologie gagnerait en précision et en exactitude, et son progrès serait assuré. On a déjà beaucoup fait dans cette voie, il est vrai, mais mon sentiment néanmoins est que la géologie expérimentale en est encore à ses débuts. Nous ne devrions avoir de trêve, que tous les phénomènes géologiques susceptibles de ce genre d'investigations, n'aient été mesurés avec précision, ou expliqués par des expériences de laboratoire. Trop souvent, et dans les diverses branches de la géologie, nous nous contentons de l'observation plus ou moins précise et exacte sur le terrain, quand nous pourrions la contrôler et étendre sa portée par des déterminations précises, par des données numériques, qui fourniraient des bases exactes aux déductions théoriques et pratiques.

Mais le sujet ainsi compris est trop vaste pour être envisagé ici dans son ensemble. Je me bornerai à quelques examples pris dans les deux grands groupes de phénomènes de la dynamique géologique : ils me permettront d'arriver à mon but.

Voyons d'abord les mouvements et changements qui s'accomplissent à l'intérieur du globe, et qui sont généralement désignés comme *hypogènes*. Il est évident que beaucoup de ces phénomènes pourraient être observés et enregistrés avec plus de soin et de régularité qu'on ne l'a fait jusqu'ici. Les recherches du professeur George Darwin, et d'autres auteurs, ont appris combien étaient constants, bien que petits, mais mesurables, les tremblements auxquels la croûte terrestre était assujettie. On

doit se demander si ces trépidations sont en relation avec quelque lent déplacement de la croûte terrestre, et dans ce cas, quelle est leur résultante sur le niveau de la surface, dans l'intervalle d'un siècle ?

Un autre fils de l'illustre Darwin a établi récemment un appareil enregistreur sur l'une des lignes de dislocation du sol du sud de l'Angleterre, cherchant à constater s'il se produisait des mouvements du sol, de l'un ou l'autre côté de cette ligne de division. Des instruments de ce genre seraient avantageusement installés dans d'autres pays, notamment dans les régions affectées d'importantes failles récentes. Il serait important et intéressant de reconnaître si, à la suite d'un tremblement de terre, il s'est produit quelque dénivellation, de part ou d'autre d'une de ces failles.

Les tremblements de terre ont été l'objet de nombreuses études, et cependant il s'en faut beaucoup que nous possédions une explication suffisante et adéquate de la cause du phénomène. Dans la plupart des cas, d'ailleurs, ils n'ont été étudiés que lorsqu'ils avaient cessé de se faire sentir ; et l'installation d'appareils enregistreurs, de séismographes, a donné une clarté et une précision nouvelles à nos conceptions concernant la nature de ces mouvements. Ces observations, toutefois, ne pourront donner de résultat satisfaisant que lorsqu'elles auront été poursuivies sur de vastes espaces et pendant de longues périodes. Déjà l'Association Britannique pour l'Avancement des Sciences a fondé une Commission Séismologique ; ses instruments enregistreurs fonctionnent en plusieurs parties du monde et servent la science, sous l'inspiration de M. Milne. Le Japon a déjà fait beaucoup dans cette voie et nous sommes fondés à attendre de nouveaux services du Survey Vulcanologique, dirigé par le professeur Koto. Le Congrès géologique international pourrait voir s'il ne serait pas possible d'installer un autre Survey semblable, en quelque autre pays exposé aux tremblements, et il pourrait chercher à unifier les observations relevées dans les divers pays ; il fournirait de la sorte un fonds solide et bien documenté à toutes les dissertations sur les tremblements de terre.

Les relations des tremblements de terre avec la formation des montagnes sont également susceptibles d'être élucidées par des mesures exactes. Les secousses séismiques, si frequentes suivant les chaînes de montagnes, doivent-elles être considérées comme la continuation et la suite des processus qui ont déterminé la formation de ces chaînes ? Et ces déplacements, dans quel sens s'opèrent-ils, ont-ils pour résultat un mouvement d'élévation ou d'affaissement ? Nous ne pouvons actuellement répondre à ces questions, mais leur solution se présentera d'elle-même, le jour où nous aurons soumis les phénomènes séismiques à des mesures précises. Des mouvements et déplacements, insensibles à l'œil de l'observateur, seront mis en évidence par des séries répétées de mesures d'altitude minutieuses, au dessus d'un repère bien choisi. Ces chiffres s'ils étaient d'une exactitude absolue, permettraient par exemple de déterminer, s'il s'est produit, en quelque point, un changement d'altitude, après un tremblement alpin. Avec de semblables données, nous serions en mesure de fixer si la grande ride terrestre des Alpes, continue encore à s'élever ou si au contraire elle s'abaisse, et nous pourrions indiquer la vitesse du mouvement. Si ces mouvements sont lents, trop lents pour être appréciables aux sens de l'homme, depuis qu'il observe, c'est une raison de plus pour les mesurer exactement, comme des phénomènes continués pendant des périodes immenses.

Ces mesures ne nous apprendraient pas sans doute si les chaînes de montagnes sont nées dans une convulsion gigantesque, ou si elles se sont dressées en plusieurs fois, par des soulèvements répétés, ou enfin si elles se sont élevées tranquillement d'un mouvement lent et continu ? Mais elles nous mettraient au moins en possession d'informations suggestives, sur la vitesse des mouvements d'oscillation de la croûte terrestre.

D'autre part, il est bien certain que le genre d'observations nécessaires pour obtenir ces résultats ne saurait être une œuvre personelle. Pour l'entreprendre et pour aboutir, il faudrait s'assurer le concours d'un ensemble de collaborateurs espacés sur toute la longeur et sur les deux versants d'une grande chaîne

montagneuse. Leurs observations devraient se poursuivre suivant un plan uniforme, méthodique, convenablement mûri, qui laisserait à chacun l'indépendence de ses efforts individuels, mais assurerait la communauté de but. Il nous paraît que l'organisation et le contrôle d'une entreprise de ce genre fournirait un but élevé d'activité à un Comité du Congrès géologique international.

Il y a une autre branche de géologie dynamique, une autre série de mouvements hypogènes dont les Congrès internationaux pourraient encore s'occuper avec succès ; et j'ai ici l'assurance de mon expérience personelle. C'est la question souvent disputée de l'origine des cordons littoraux ou plages soulevées, si caractéristiques des rivages marins du N. W. de l'Europe. Les géologues sont toujours aussi divisés relativement à l'origine de ces terrasses remarquables ; certains y voient des preuves d'abaissement du niveau de la mer, d'autres les considérant comme démontrant le soulèvement du sol continental. Il semble cependant qu'on ait négligé jusqu'ici de déterminer la condition fondamentale et essentielle, nécessaire à la solution de ce problème : de bonnes mesures.

Sans doute, on a des mesures locales, suffisamment précises et exactes, du niveau de ces plages, mais elles sont isolées et disséminées ; elles devraient au contraire être généralisées et étendues à de vastes régions, pour permettre des conclusions définitives. Il faudrait ici lever une série de nivellements rigoureux des plages soulevées, en les repérant exactement sur toute leur étendue, relativement à la ligne des côtes.

Ainsi, par example, en Ecosse, il y a deux de ces terrasses bien marquées, l'une à l'altitude d'environ 50 pieds, l'autre à environ 100 pieds, au-dessus du niveau actuel de la mer. Ces deux terrasses se retrouvent à E. et W. sur les deux rivages du pays, paraissant conserver les mêmes altitudes ; or, on n'a point encore fait de nivellement systématique qui permettrait de reconnaître la constance ou la variation de leurs niveaux, soit d'un côté ou de l'autre du pays, soit dans la direction du N. au S. — Ces deux terrasses disparaissent l'une comme l'autre,

au Nord, on ne les voit pas non plus au Sud, en Angleterre; on remarque en outre certaines inégalités apparentes de niveau, suivant leur parcours, ce qui semble indiquer qu'elles ont été sollicitées par des mouvements inégaux. Mais avant que ces différences aient été mesurées avec précision, je n'estime pas qu'un savant soit fondé, d'après ce qu'on observe en Ecosse, à conclure que le niveau de la terre s'est élevé, ou que celui de la mer s'est abaissé. J'espère que cette question spéciale sera élucidée chez nous, d'une façon satisfaisante, et j'ai déjà pris des dispositions à cet effet; mais sa solution ne suffira pas pour asseoir une conclusion générale. Elle devra être étudiée comparativement dans d'autres pays. Il serait désirable que sous l'impulsion et sous les auspices des Congrès géologiques internationaux, les géologues danois, norwégiens, suédois, finlandais, russes, écossais, américains, entreprennent d'un commun accord un lever détaillé, qui fixe, d'une façon définitive, ce problème des lignes littorales de l'hémisphère boréal.

Je passerai maintenant à la considération de quelques exemples choisis dans l'autre classe de la dynamique géologique, parmi les *phénomènes épigènes;* là encore on trouverait de grands avantages à généraliser les méthodes préconisées de mensuration et d'expèrimentation.

L'ètude des phenoménes de dénudation nous ouvrira un champ illimité, quoique de toutes parts déjà il ait été défriché avec activité et avec succès. Des volumes, des mémoires, des articles de toute forme, ont été consacrés à l'étude de ces phénomènes de dénudation; et cependant, dans cette riche littérature, il y a pauvreté assez générale de précision, absence presque constante de résultats numériques, rareté des mesures exactes, systématiques ou continues, en un mot défaut habituel des données qui permettraient de se rendre un compte véritable de l'étendue et de la rapidité des dénudations observées. Il y a toutefois des exceptions honorables, et nous possédons bien quelques mesures exactes de la plus haute valeur, et leur nombre s'accroît encore tous les jours, mais quel avantage il y aurait, pour la science, à le décupler!

C'est qu'en effet quand on envisage la sculpture et les formes d'altération des traits terrestres sous l'influence de la dénudation, il semble qu'il y ait cent moyens de contrôler l'observation immédiate des phénomènes, par des mesures directes, ou par des expériences de laboratoire.

C'est presque un lieu commun de dire, en géologie, que la quantité de substances enlevées en suspension ou en solution par les cours d'eaux, mesure l'importance de la dénudation des régions drainées par ces rivières. Et cependant combien inégales, et combien insuffisantes en général sont les indications numériques que nous possédons sur cette importante question! On n'a encore étudié systématiquement, à ce point de vue, qu'un très petit nombre de rivières, et les résultats discordants ne peuvent être considérés comme définitifs. Ils ont suffi seulement à montrer l'intérêt et toute l'importance de cette méthode de recherche; mais on n'est pas encore en possession de documents suffisants pour en tirer des déductions rationnelles, moins encore des généralisations.

Ce qu'il nous faudrait pour cela, c'est une série d'observations bien menée, organisée suivant un plan uniforme, poursuivie pendant plusieurs années, et étendue à toutes les rivières d'un pays, voire même à toutes les grandes rivières des divers continents, loin d'être limitée à un seul cours d'eau. Il importerait de connaître, aussi exactement que possible, l'étendue et la surface du bassin des rivières, les relations de leur débit avec les quantités de pluie, le détail de toutes les conditions météorologiques aussi bien que des topographiques, les variations dans les proportions des matières suspendues ou dissoutes dans leurs eaux, relativement aux formations géologiques traversées, à la forme du fond, à la saison, au climat. En un mot, il faudrait connaître en détail le régime de toutes les rivières. On peut citer, comme modèle du genre, l'admirable rapport de MM. Humphreys et Abbott, sur les "Physics and Hydraulics of the Mississippi" publié en 1861, bien que ces auteurs, préoccupés de diverses questions étrangères à la géologie, aient laissé dans l'ombre certains points d'un grand intérêt pour nous.

Ce que nous avons dit de l'étude des Rivières s'applique exactement à celle des Glaciers. Il semble, il est vrai, que les lois qui régissent le mouvement des glaciers aient été amplement approfondies, et qu'on ait relevé avec soin leurs mouvements d'avance et de retrait. Mais ce sont des côtés de la question plus intéressants pour le physicien et le météorologiste. Nous, nous devons réclamer, comme géologues, des informations plus précises sur le labeur géologique des Glaciers. Il nous importe de mieux connaître la vitesse avec laquelle ils creusent leur voie, les circonstances qui favorisent ou retardent leur puissance érosive, les conditions qui leur permettent de remonter des pentes, et enfin la réalité et l'importance des mouvements, en sens divers, qui se produisent dans la glace, et par suite desquels les cailloux sont charriés et les stries sont orientées dans des directions variées. Ce sont autant de questions, et il en est beaucoup d'analogues, sur lesquelles nous ne possédons que des renseignements vagues et incertains. Il semble cependant que leur solution dépende d'une série d'observations systématiques, suffisamment prolongée, à condition qu'elles ne soient pas bornées à la Suisse, mais poursuivies en Scandinavie, dans les Régions arctiques et antarctiques, aux Indes, à la Nouvelle-Zélande. Notre Congrès International a déjà marché dans cette voie, et créé un Comité des Glaciers qui, sous l'impulsion enthousiaste de M. Forel, a déjà rendu des services signalés. Ce Comité est digne que nous nous intéressions à lui et que nous encouragions ses efforts, il y aurait avantage à le développer, pour qu'il étende son action à toutes les régions du globe accessibles aux géologues. Ainsi les savants danois qui, dans ces dernières années, ont tant ajouté à nos notions sur les glaciers et les nappes glacières du Groënland, les géologues américains qui ont fait de si bon ouvrage parmi les glaces de l'Alaska, seraient d'excellentes recrues pour notre Comité des Glaciers; et il y a lieu de croire qu'il suffirait d'une simple invitation pour qu'ils poursuivissent de concert avec nous, les mêmes recherches systématiques.

Un autre sujet d'étude qui a attiré à maintes reprises l'attention des géologues, est celui de la Dénudation Subaérienne de la

croûte terrestre. Et cependant nous manquons aussi de documents précis ; on n'a pas encore mesuré son action comparativement, avec précision et méthode, sur les différentes roches, et sous diverse climats. On pourrait s'aider dans cette mesure de l'examen de bâtiments, portant la date de leur construction ; j'ai pu ainsi indiquer, il y a déjà 20 ans, la rapidité de la désagrégation de certaines roches dans un climat humide et variable comme celui de l'Ecosse. On a cependant jusqu'ici peu fait, dans cette voie.

L'étude de la dénudation ne peut guère se séparer de celle de la sédimentation : les matériaux déposés par la sédimentation sont ceux qui on été enlevés par dénudation, moins ce qui a été dissous en route, dans les eaux des ruisseaux ou de la mer. Or, il nous reste beaucoup à apprendre sur les conditions de la sédimentation, et ses variations de vitesse.

Il ne semble pas qu'on puisse compter sur de notable progrès dans cette étude, aussi longtemps qu'on ne l'abordera pas systématiquement, au moyen d'un plan préconçu, bien mûri et poursuivi avec continuité. Il y a encore bien des inconnues pour nous, dans la forme et la rapidité des dépôts qui s'accumulent sous l'influence des divers facteurs, dans les lacs, les estuaires et la mer. Ainsi nous ne saurions indiquer par une moyenne, la vitesse avec laquelle se comblent les lacs des divers pays d'Europe. Si d'ailleurs nous connaissions cette vitesse, et si nous savions, d'autre part, la quantité de sédiments déjà amassée, nous aurions en notre possession un moyen de calculer, non seulement en combien de temps ces lacs seront comblés et disparaîtront, mais aussi, ce qui est plus important, depuis combien de temps leur remplissage se poursuit. Ce chiffre en effet, nous fournirait une date, pour la fin de la Période Glaciaire. Des conclusions de cette nature ne sauraient découler d'observations isolées ou locales, elles doivent être basées sur les observations combinées de nombreux observateurs, des diverses régions lacustres du continent, suivant un plan déterminé.

La géologie est entrée dans une période où on doit attendre les plus grands avantages de méthodes d'investigation plus précises, de la convergence des efforts individuels, librement associés

sous une même règle, et vers un même but. Il serait aisé d'en multiplier encore les exemples. Mais nous croyons en avoir dit assez, pour faire voir au Congrès la portée de ces tentatives, et l'importance que nous y attachons. Nous ne proposerons pas toutefois ici de plan général d'organization, notre intention actuelle étant de nous borner à une sorte de consultation, et de demander à nos confrères s'ils pensent avec nous qu'il serait bon, avantageux, et praticable d'installer sur des bases plus larges la coopération en géologie? J'estime que nous aurions rendu un service durable à la science, si nous arrivions à grouper des observateurs en comités d'action, travaillant avec méthode, vers un but déterminé, soit l'un de ceux que je viens d'indiquer, ou tout autre. Il y aurait même de la prudence à débuter par la question la plus facile, celle qui réclamerait la moindre dépense d'hommes et d'argent. On pourrait partager la besogne, entre les divers pays représentés au Congrès. Chaque pays pourrait librement choisir le sujet de ses observations, n'étant poussé que par l'émulation de voir ses voisins avancer dans la même voie.

Un Comité Central composé de members des diverses nations engagées dans ces recherches sur le terrain, rendrait des services en traçant les méthodes générales, les plans de travail, et en indiquant le but. Son rôle se bornerait à organiser le travail et à généraliser la méthode, en laissant la plus grande latitude possible aux efforts individuels.

La publication des résultats ne serait pas non plus soumise à l'appropriation du Congrès Chaque collaborateur, chaque comité resterait libre de suivre ses convenances, et on se bornerait à présenter à nos sessions, tous les trois ans, un aperçu sommaire des résultats généraux. Nous avons la confiance que ces résumés, publiés par nos Secrétaires et insérés dans nos Comptes-Rendus, constitueraient un des chapitres les plus importants de nos volumes triennaux. L'idéal d'une assemblée comme la nôtre ne saurait être de contrôler le progrès, mais bien de l'encourager, et de favoriser le groupement et l'association de toutes les initiatives internationales.

ARCHIBALD GEIKIE.

PROPOSED INTERNATIONAL GEOLOGIC INSTITUTE[1]

It is a source of profound regret that imperative circumstances prevent my attendance at what I am sure will be a most important session of the International Geological Congress. Forbidden this pleasure, I venture to show my interest by offering some suggestions relative to a line of effort tributary to the leading purpose of the congress. At the first session of the congress in 1878, which I had the pleasure of attending, a dominant theme of discussion was geologic classification, and this continued to be the foremost theme for subsequent sessions until it was found impossible to agree upon any system proposed. It furthermore developed that many of the most able and experienced geologists were of the opinion that it was premature to attempt any authoritative action in the matter, since in their judgment the groundwork for a *permanent* classification was not yet sufficiently broad and firm, and they felt much apprehension respecting the trammeling effects of sanctioning a premature classification. Thoughtful geologists who have given the matter careful study will quite generally agree that much is yet to be learned of fundamental facts and principles before a classification can be authoritatively adopted as the mature judgment of the geologists of the world without great risk of hampering the progress of true classificatory ideas. It seems not unlikely, therefore, that an authoritative adoption of a general classification will continue for some time to be regarded as a great end to be ultimately reached, but not wisely attempted until the foundation is better laid.

In the meantime, what can be done to hasten the great achievement?

A true classification of geologic history must represent its *natural* divisions, if there be such natural divisions. In the judgment

[1] Presented to the eighth session of the International Geological Congress at Paris, August 1900.

of some geologists there are no natural divisions that hold good beyond limited provinces. They recognize no general divisions of a sufficiently definite kind to serve the purposes of a concrete classification. In their judgment the succession of geologic events was a continuous progression. They admit that it was differentiated locally and even continentally, but not so universally as to furnish a good basis for classification. They recognize that the existing classifications are natural in some degree as applied to Europe and America, the regions upon which they have been founded, but they anticipate that they will prove quite arbitrary as applied to other continents and to the world as a whole. Entertaining these fundamental views, they hold that classification should be regarded merely as a convenient arbitrary device, and that the existing systems should give way to a more convenient one, much as the old systems of measurement are giving way to the metric system.

On the other hand, there are those who regard the history of the earth as naturally divisible into important stages whose recognition constitutes a leading function of philosophic geology. None of these contend that there was at any time a universal cessation of sedimentation or a complete break in the continuity of life. They freely admit and affirm that there is a fundamental continuity, but at the same time they hold that progress was not uniform, but pulsative or rhythmical. Specifically, speaking for some of these, they think they find periods of stress-accumulation followed by periods of stress-relief, periods of land-expansion followed by periods of sea-transgression, periods of topographic accentuation followed by periods of base-leveling, periods of climatic uniformity followed by periods of climatic diversity, periods of biologic luxuriance followed by periods of biologic impoverishment, in short, a pulsative progress whose successive phases furnish a natural basis for classification.

The existence of these diverse views is an expression of the imperfection of present knowledge. Were exhaustive data at command it could be determined whether the dominant character of the earth's progress was uniformity or periodicity, and hence

whether we should primarily seek a scale of reference and nomenclature with a uniform arbitrary unit, as the meter or the century, or whether we should strive to measure progress by its inherent waves or nodes, or whether we should seek both impartially.

If the rhythmical view be the most laudable, effort should be directed to the more complete and accurate determination of the nature and limits of the periodicities, and to the modification of present classification, so as to bring it into more complete conformity to these. If the uniformity view be the more laudable, effort should be directed to reducing the adopted divisions to quantitative equality by perfecting the geological column and determining available scales of measurement, both stratigraphic and chronologic.

In either case, or in any other case which any individual geologist may prefer to put in the place of these selected ones, it is necessary to push investigation a long way forward before an International Congress can wisely give its sanction to any specific classification.

Our shortest road to the great end sought will therefore be found in promoting those investigations which will soonest give the needed groundwork. Fortunately these investigations are precisely those which best subserve the higher philosophic purposes of the science. Two phases of this great work stand forth prominently: (1) The systematic compilation and elaboration of the great mass of data produced by studies in all parts of the world, which are not now fully available, save to a few favored workers connected with the great libraries, and to these only through much labor duplicated in every individual case. It will be admitted without discussion that the collocation and organization of existing and forthcoming data would greatly stimulate accretions and promote the end sought. (2) *The development of additional criteria of correlation. A preëminently essential step in the progress of classification and interpretation is an increase in the precision and the certainty of correlation of formations in widely separated regions.*

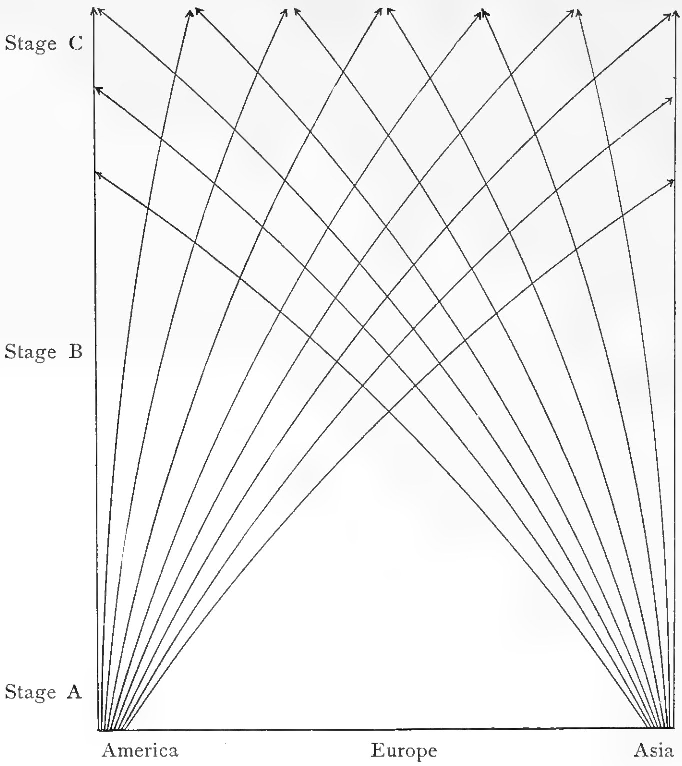
At present the general conviction prevails that there is but a single trustworthy basis of correlation between separated regions, and that even this is subject to some important qualifications, and in many cases is wholly unavailable. I need not mention fossil contents. But while fossils are, and apparently must ever remain, the chief means of correlation, it has been the growing conviction of my recent years that certain important improvements and extensions of the criteria of correlation are possible. These embrace (*a*) an improvement of the paleontologic criteria by correcting them for the uncertainties and errors introduced by migration; and (*b*) the addition of physical criteria to the paleontologic ones in such a way as to eliminate some of the uncertainties of the latter, and to serve in their place when they are not available, as is so often the case.

It is neither appropriate nor possible to set forth these adequately here, but I should fail to duly magnify the importance of the measure herein advocated if I did not at least try to indicate the greatness of the possibilities which we might hope to realize if we had the means at our command.

(*a*) The line of improvement in paleontologic correlation may be best illustrated by a concrete example. Let it be supposed that a provincial fauna arises in a harbor of refuge during a time of sea-withdrawal from the continental shelf[1] on the border of America in a given stage A; that by the subsequent development of an adequate sea-shelf or a connecting series of epicontinental seas, this fauna migrated to the shores of Europe during stage B, and that ultimately it reached the coast of Asia in stage C. By the simple application of the criterion of community of species, stage C of Asia would be correlated with stage A of America, and although the time-interval might not be very great, the error growing out of it might seriously disconcert the correlation of associated physical events, and prevent their correct interpretation. But if during the stage A there developed in a harbor of refuge on the coast of Asia another provincial

[1] "A Systematic Source of Evolution of Provincial Faunas," JOUR. GEOL., Vol. VI, No. 6, Sept.-Oct. 1898, pp. 604–608.

fauna, and if this, for like geographic reasons, was permitted to reach Europe in stage B, and America in stage C, a different set of errors of interpretation would be likely to arise from the simple criterion of community of species, for the commingled faunas would appear in America and Asia only in stage C, while they would appear in Europe as early as stage B. So too, in



America and Asia, in stages A and B, only the respective provincial faunas would be found. The situation is illustrated in the accompanying diagram. But if the fact of the provincial origins of the two faunas and their subsequent migration can be established, a much more accurate correlation will be possible. The deposits of stage A in Asia and America will be correctly

assigned to the same period, though they have no species in common, and the other stages will fall into their proper sequence. This may suffice to illustrate one method by which the migration, *and particularly the cross-migration*, of faunas may be brought into service in the correction of the errors of correlation arising from dependence simply on the presence of common fossils. It will furthermore be recognized with acclaim that the tracing out of the origins and migrations of the ancient races of the earth's inhabitants has independent and profound interest, and that it is peculiarly and necessarily an intercontinental work.

But the origin and migration of faunas and floras is peculiarly dependent on physical conditions. I am persuaded that this is most eminently true of the origin of provincial faunas and their evolution into cosmopolitan faunas, as I have endeavored to set forth in recent papers.[1] While it will doubtless always be quite difficult to detect the point of origin and the course of migration of *single species*, there is reasonable ground of hope that the origin of provincial *faunas* may be located, and their migrations and fusions followed until they are lost in cosmopolitan faunas. I have given reasons elsewhere for believing that the general production of provincial marine faunas of the shallow-water type is connected with the withdrawal of the sea from the upper face of the continental platforms, associated with surface warpings, by the first of which the areas of shallow water are restricted, and by the second dissevered from each other.[2] It is therefore believed that much aid in rendering paleontologic interpretations more significant, more certain, and more precise may be derived from the study of the bodily movements of the earth and of the evolution of the geography of the continents in their migratory relations. Certainly and admittedly

[1] "The Ulterior Basis of Time Divisions and the Classification of Geologic History," JOUR. GEOL., Vol. VI, No. 5, July-August 1898, pp. 449–526.

"A Systematic Source of Evolution of Provincial Faunas," JOUR. GEOL., Vol. V, No. 6, Sept.-Oct., 1898, pp. 597-608.

"The Influence of Great Epochs of Limestone Formation on the Constitution of the Atmosphere," *Ibid.*, pp. 609–621.

[2] The first two papers above cited.

this is eminently true of land faunas whose migrations are essentially dependent on terrestrial connections, and I believe it is scarcely less true that the migration of the more immobile portion of shallow water sea faunas is dependent on continental shelves and epicontinental seas. If, therefore, there be a periodicity in the great bodily movements of the earth and sea, and a consequent periodicity in the origination of provincial faunas, there will be all the greater field for the application of principles founded on migration and counter-migration to the working out of more precise correlations.

(*b*) There is reason to hope that the sea itself may be made an important aid in intercontinental correlation, for it makes, and always has made, *a simultaneous record on all the continents.* The difficulties lie solely in reading the record.

The ocean volume may not have been accurately constant at all times, but its variations between closely related periods can never have been more than a negligible fraction of the whole volume. Its record is made on the border of a single complex basin, for all the oceans are united and have a common water level. Apparently there has always been essentially a single complex basin, though this cannot be rigorously affirmed. Assuming it, however, any deformation of the basin in any part, which affects its capacity, is recorded on all continents by a new shore line. Setting aside compensatory warpings, this involves a universal advance or retreat of the sea, and a corresponding change in the areas of sedimentation and erosion. It involves, also, a change of land and sea faunas by expanding and contracting their habitats respectively, and by extending or restricting their means of migration. Were it not for the attendant warpings of the land, these sea changes would furnish a simple means of world-wide correlation of the most precise and specific kind. Conjoined with paleontology they would leave little to be desired so far as marine stages are concerned. There remains, however, the problem of eliminating the disturbing effects of concurrent warping. To some large extent it is the warping that changes the capacity of the ocean basins. Warping may even disturb

the local attitude of the land to the sea without affecting the capacity of the ocean basin, for the warping up in one region may be compensated by the warping down in another region. The subject is therefore attended by grave difficulties, but it is not without sufficient ground of hope to justify systematic study. There are at least two general phases of earth-action whose effects promise to rise above those of local warpings to such a degree as to be determinable and to be serviceable in intercontinental correlation. They are the stages of great shrinkage and the stages of relative quiescence. Whatever views may be entertained of the early history of the earth or of its internal constitution, it will probably not be questioned that the oceanic bottoms have, on the whole, shrunk more than the continental platforms. The very existence of the continents in spite of erosion is an expression of this. It will perhaps not be denied that the shrinkage adjustments of the exterior of the earth have been periodic and that the basins have been deepened and the land relatively elevated at the periods of adjustment; at any rate, this may be made a working hypothesis, coördinately with its opposite, until the truth is ascertained.

Between the assumed periods of adjustment, periods of relative quiescence may be recognized as their necessary complement. These were only relatively quiescent, for local and regional warpings were quite certainly in progress at all stages of geological history. In these stages of relative quiescence the volumetric erosion of the land may quite safely be assumed to have exceeded the volumetric elevation, and the material transported to the sea may be assumed to have exceeded any increase of the capacity of the ocean basin due to shrinkage. Without these assumptions it seems to me difficult to explain specifically the history of erosion and sedimentation; but, as this may be doubted, let the assumptions stand merely as working hypotheses. The result of such erosion would be the partial filling of the common ocean basin and the extension of the sea upon the land. Taking Murray's estimate of the present average height of the land, a volumetric reduction and transference of one half

the protruding portion would raise the sea level somewhat more than one hundred meters, an amount sufficient, in the lowered state of the continents, to notably extend the marine area and change the distribution of life.

Here, then, hypothetically are two systematic causes tending to produce universal changes in the relations of sea to land, the one dependent on the accumulation of shrinkage stresses by reason of the effective rigidity of the earth, and the other dependent upon erosion during relatively quiescent stages. Now, if by the compilation of great masses of data the disturbing effects of local warping can be eliminated, a means of intercontinental correlation, independent of the paleontologic, and fundamental to it, may be obtained. By combining the dynamic with the paleontologic the testimony of both may be enhanced and the significance of the latter greatly increased.

The application of the method obviously requires the massing and handling, quantitatively as well as qualitatively, of all possible data from all parts of the world, and can only give results of the highest order of trustworthiness when the mapping of the whole earth approaches completion, but there is reason to believe that initial results of no small value might even now be secured if all existing data could be marshaled.

The constitutional states of the atmosphere furnish a third source of hope of supplementary means of correlation. If the view that the atmosphere originally contained all or the larger portion of the elements which have been taken from it, notably the carbon dioxide, and that its history has been one of continuous depletion, and that, aside from a slow decline in temperature, climatic changes have been due merely to local agencies, be correct, there is little ground of hope for results of much value in correlation. But if, on the other hand, as recently postulated,[1]

[1]A Group of Hypotheses Bearing on Climatic Changes. JOUR. GEOL., Vol. V, No. 7, October-November 1897.

The Influence of Great Epochs of Limestone Formation on the Constitution of the Atmosphere, JOUR. GEOL., Vol. V, No. 6, September-October 1898, pp. 609–621.

An Attempt to Frame a Working Hypothesis of the Cause of Glacial Periods on an Atmospheric Basis, JOUR. GEOL., Vol. VII, Nos. 6, 7, and 8, 1899.

the carbon dioxide of the atmosphere has been mainly supplied concurrently with its consumption, and the amount has varied with the ratios of supply to consumption, and these ratios have been dependent upon the extent of the land and the condition of the sea, and if further the impoverishment of the atmosphere in carbon dioxide is determinable by the unusual prevalence of certain kinds of deposits, as salt, gypsum, red clastics, and glaciated bowlder clays, while its enrichment is indicated by equable temperatures and mild climates in high latitudes, there is ground for hoping that the constitution of the atmosphere may be made to afford a valuable means of correlation applicable when the paleontologic criteria are most liable to fail. Effects due to the constitution of the atmosphere must be universal and strictly simultaneous, though of course not everywhere identical. For example, in India, Australia, and South Africa, an abrupt change in the flora took place at some time near the transition from the Carboniferous to the Permian period. Fontaine and White have found an abrupt, though less radical, change in the flora of eastern America at about the same time, but there are no paleontological means at present known by which these changes can be accurately correlated. The change in India, Australia, and South Africa is closely associated with glacial deposits. Now, if glaciation be a result of a *constitutional* state of the atmosphere, such state should make itself felt *in all parts of the earth simultaneously*, though in different ways and degrees, and the floral change in eastern America could with good reason be strictly correlated with the changes in Asia and the southern hemisphere, and should find verification in similar changes elsewhere. This is merely a hypothetical illustration. The supposed atmospheric mode of correlation should be verifiable by its peculiar effects, for it should simultaneously affect distant floras made up of different constituents, a phenomenon differing in nature from the effects of simple migratory replacement or biologic evolution.

It is obvious, however, that correlation by atmospheric states can only become a trustworthy dependence by the

massing and careful adjudication of data from all parts of the world, for the sanction of the method will largely depend on its success in conforming to and elucidating world-wide phenomena. Both this and the preceding method will require first to be established by trial before they can be independently applied, but this was equally true of the paleontologic criteria at the outset.

The very establishment of these atmospheric and oceanic criteria, or their disproof, would go far to settle the fundamental question whether the earth's history is naturally divisible into periods or not. If there be secular accumulations of stress in the body of the earth, followed by adjustments when rigidity is overcome, and if these adjustments change the respective areas of land and sea, and these in turn result in changes in the constitution of the atmosphere and in the evolution of life, these cycles must be factors in the ultimate basis of a rational classification of geologic time, and must at the same time express some of the most profound and significant features of the earth's history.

The doubt as to whether these things be so or not can only be resolved by studies as broad as the earth. Such studies are not only international and intercontinental, but they are omniterrestrial. The shaping they have been given here is that of an individual student and expresses his limitations, but the breadth and importance of the problems themselves will not be questioned.

Now it is far beyond the functions and the resources of any present official organization to adequately cope with these great problems. There is not even an organization at present that is provided with the men and the means to bring promptly together, arrange, and tabulate for the common benefit of geologists the data that are being gathered by official and private investigations; much less is there any organization that can build these into their organic relations, or draw forth from them their full significance and make this serviceable in further investigation. Nor is there any organization provided with any notable means

for systematically supplementing the work of official and private surveys where such auxiliary work is most needed. A few universities and a few generous individuals provide means for particular expeditions and these have great value and should command our profoundest appreciation, but they are not, and cannot be expected to be, systematically related to classification or to the other general questions under the special patronage of this body.

I beg to urge, therefore, upon the International Congress the inauguration of a systematic movement looking to the determination of the fundamental facts upon which an ultimate classification may be founded.

The practical suggestion I ask leave to offer is an appeal to the generous people of our several nations for the means to establish a permanent institute, or group of coördinate institutes, which shall be devoted to this purpose and to others germane to it. Specifically these purposes may be summarized as follows:

1. The collocation, systematic arrangement, and publication of existing and forthcoming data bearing upon the fundamental facts and principles upon which a final classification must be founded.

2. The gathering of literature, especially that now least accessible, and, so far as practicable, of typical collections bearing on the special objects of the organization.

3. The elaboration of data by combination, computation, and correlation, both independently of all hypotheses and in specific application to the various hypotheses that may be propounded.

4. The encouragement, and so far as practicable, the conduct of field investigations in regions not cultivated by existing organizations, nor reached by private enterprise.

The magnitude and duration of the work would require that the institution be permanent. If the task of the complete correlation of the earth's formations be assumed it is doubtful if the function would ever be entirely fulfilled.

The generosity with which great institutions of learning have been founded and expensive scientific expeditions equipped gives encouragement to the hope that if the noble object were suitably made known, the means for its realization would be forthcoming.

It may seem premature to discuss details of organization and modes of control before the general nature of the proposition is approved, or substantial encouragement be given that the necessary means of carrying it into effect will be available, but the practicability of the proposition is in some measure dependent on the concrete form which it would take. This is a peripatetic body of changing membership, and, so far forth, is not most happily organized to administer an enterprise of this kind. The congress, furthermore, represents many nations and could not be hoped to be entirely at one as to the location and control of a permanent institution of this kind. It is, furthermore, probable that patrons of the proposed organization would be influenced by patriotic sentiments in making contributions to the endowment. It seems best, therefore, to recognize these conditions in the proposition itself, and instead of endeavoring to establish a single international institution under the specific control of this body, to urge the establishment of sections or branches or coöperative members of a composite organization to be located in as many nations or grand divisions of the globe as future developments might render wise; these sections or branches to be immediately administered by such bodies in such nations or grand divisions as were found most suitable and practicable. For example, in America, a section or a coöperative institution might well be established under a board of trustees elected by the Geological Society of America, a permanent organization of definite membership, representative of geological activity on the North American continent. Similar representative societies or fixed geological organizations fitted for the control of other branches or coöperative institutions exist, or if not, should be brought into existence, in all the great nations or grand divisions. Such regional organizations would possess certain advantages in the

collection of data from the fields they would specially represent. The function of the International Congress would embrace the inauguration and coördination of these, the advisory control of their lines of effort, the adoption of their partial results as reached from time to time, and the creation of international sentiment in their support.

T. C. CHAMBERLIN.

UNIVERSITY OF CHICAGO,
July 25, 1900.

THE COMPOSITION OF KULAITE

SEVERAL years ago I published[1] as an inaugural dissertation an account of the volcanoes of Kula, in Lydia, Asia Minor. In this the recent lavas of the region were described, to which rocks the name of "Kulaite" was given, the definition being, "a subgroup of the basalts which is characterized by the presence of hornblende as an essential constituent, which surpasses the augite in quantity and importance." The varieties of leucite-kulaite and nepheline-kulaite were also recognized, the essential character of all being the predominance of hornblende over augite.

Although the analysis made for me by Dr. Röhrig showed, for basalts, abnormally high Na_2O, yet little attention was paid to this feature and, attempts at identifying nepheline in the groundmass having failed, the kulaites were regarded essentially as plagioclase-basalts in which the pyroxene was largely replaced by hornblende.

In his latest book, Rosenbusch[2] recognizes this combination of high alkalis with a basic combination, and refers them to his group of trachydolerites, an intermediate group corresponding to the latities of Ransome,[3] which are effusive equivalents of the monzonites and intermediate between trachytes and andesites or basalts.

Study of other rocks of Asia Minor, which also showed similar latitic features, as well as the growing importance of these intermediate types, also called my attention again to the Kula rocks, and led to a reëxamination of them. This seemed

[1] The Volcanoes of the Kula Basin, in Lydia, New York, 1894.

On the Basalts of Kula, Amer. Jour. Sci., Vol. XLVII, p. 114, 1894.

[2] ROSENBUSCH: Elemente der Gesteinslehre, p. 342, 1898.

It is uncertain whether Rosenbusch understood these rocks to be without any feldspar at all, or only without feldspar phenocrysts.

[3] RANSOME: Amer. Jour. Sci., Vol. V, p. 373, 1898.

especially needful chemically, since, as was pointed out to me by Professor Iddings, judging from the description published in 1894, there seemed to be no mineral present which would account for the high alkalis. In addition, for such basic rocks, Al_2O_3 seemed to be very high and MgO very low, and it was feared that Dr. Röhrig had made the common error of precipitating some MgO along with the Al_2O_3. I am happy to be able to say that two analyses, made by me with especial care in regard to this point, show conclusively that in this respect Röhrig's analyses are quite correct.

As the rocks have been already described, it is not necessary to go into any lengthy account of their mineralogical features, and only the two analyzed will be mentioned.

The rock from a depth of 35 meters in a well digging in Kula is light gray, fine grained and slightly vesicular, with small phenocrysts of olivine and pyroxene visible. In thin section phenocrysts of pale gray pyroxene (diopside), olivine and of hornblende, which last in every case have been completely altered to a mixture of diopside and magnetite, are seen lying in a holocrystalline groundmass. This is composed of bytownite laths, small crystals and anhedra of diopside, magnetite grains and small apatites, with an ill defined, colorless mesostasis of low refractive index and small birefringence, which was previously referred to accessory orthoclase.

The tests made in Leipzig failed to reveal the presence of nepheline, but these have been lately repeated with care, and they prove beyond question that part of this interstitial, anistropic substance gelatinizes with acid and stains with fuchsine, while part of it remains unaffected. It is therefore established that nepheline is present in this rock, a conclusion in accordance with the results of analysis, as will be seen later.

A second specimen to be described is of a "leucite-kulaite," from the northeast flow of Kula Devit,[1] near the Gediz-chai,

[1] This was spelled "devlit" in the former papers, following earlier authorities (Hamilton, Tschihatcheff) and as the word was apparently understood by the natives. It is really دويت "devit" an ink-stand, and not دولت "devlit" state or government. Cf. Inaug. Diss., p. 12.

Megascopically, this is similar to the other, but is darker gray and somewhat finer grained.

In thin section it shows fewer phenocrysts of diopside and olivine than the other, but more abundant, well-formed, hornblendes, which have all been altered, in some cases entirely, in others only partially, leaving some unchanged hornblende substance in the center. This alternation has not been as thorough as in the preceding, and, while here and there alteration to the usual diopside-magnetite aggregate is seen, in most cases the spaces formerly occupied by hornblende show a mass of the brown, pleochroic orthorhombic rods, which I have identified with hypersthene.

The groundmass is similar to the other, but flow structure is well marked. There are similar plagioclase laths (here andesine), also olivine and diopside crystals, generally stouter and better crystallized, and smaller grains of magnetite but scarcely any apatite. The most important difference is the presence in abundance of small round areas of a clear, colorless mineral, of low refractive index, and generally isotropic, containing inclusions of diopside needles and magnetite grains, arranged either centrally or zonally. While these round spots are mostly too small to show very marked abnormal double refraction, yet they occasionally do so, and there seems to be no doubt that they are to be referred to leucite. The mesostasis here is colorless and almost isotropic and glass-like, but it stains by treatment with HCl and fuchsine.

In the table are given the two analyses recently made by myself, as well as the corresponding ones of Röhrig. A few other analyses of similar rocks are inserted for comparison, and will be referred to subsequently.

It will be seen that Röhrig's analysis of the normal kulaite (II) agrees very well with mine (I) in all respects except in Fe_2O_3 and K_2O, which are respectively about 2 per cent. higher and lower. On the other hand, his of the leucite-kulaite (IV) resembles mine (III) only in MgO, CaO, and Al_2O_3, the TiO_2 present being weighed by him with the Al_2O_3. The other constituents differ rather widely.

	I	II	III	IV	V	VI	VII	VIII	IX	X	XI
SiO_2	48.35	48.24	49.90	47.74	42.68	41.01	44.77	47.83	48.24	46.48	49.69
Al_2O_3	19.94	20.64	19.89	20.95	9.42	11.58	17.82	16.09	17.43	16.16	18.06
Fe_2O_3	2.48	4.63	2.55	3.29	11.55	12.54	5.05	4.32	7.22	6.17	2.64
FeO	5.25	5.55	4.78	6.32	7.23	7.60	6.95	3.62	1.17	6.09	6.19
MgO	5.15	5.02	5.05	5.16	10.09	8.67	8.22	5.53	3.99	4.02	5.73
CaO	7.98	7.94	7.21	7.56	13.15	12.20	10.36	10.68	6.09	7.35	8.24
Na_2O	5.47	5.08	5.60	7.12	2.71	2.57	2.13	4.46	4.28	5.85	2.99
K_2O	3.99	1.88	3.74	1.21	1.16	1.45	0.92	4.05	4.62	3.08	3.90
H_2O 110°+	0.22	0.02	0.19	0.04	1.06	1.87	2.64	0.24	2.78	4.27	0.91
H_2O 110°−	0.16		0.13					0.05			
CO_2	....	....	....	....	....	....	....	....	....	0.45	....
TiO_2	0.12	....	0.93	....	0.51	0.48	0.53	2.27	2.89	0.99	0.85
P_2O_5	0.84	0.97	trace	0.13	1.29	0.75	0.72	0.47	1.33	....	0.81
Cl	....	....	....	....	....	....	....	....	....	....	0.13
MnO	trace	....	trace	....	....	....	trace	0.38	trace	....	0.13
	99.95	99.97	99.97	99.52	100.85	100.72	100.11	99.56	100.47	100.91	100.27

I. Kulaite. Well digging. Kula. H. S. Washington anal.
II. Kulaite. Well digging. Kula. A. Röhrig anal. Am. Jour. Sci., Vol. XLVII, p. 122, 1894.
III. Leucite-kulaite. Near Gediz-chai, Kula. Washington anal.
IV. Leucite-kulaite. Near Gedis-chai, Kula. A. Röhrig anal. Loc. cit.
V. Hornblende-basalt. Todtenkopfchen, Rhone. Sommerlad anal. Neu. Jahr Beil, Band II, p. 155, 1883.
VI. Hornblende-basalt. Sparbrod, Rhone. Sommerlad anal. Loc. cit.
VII. Hornblende-basalt. Kosk Creek, California. Eakins anal. Diller. Amer. Geol., Vol. XIX, p. 255, 1897.
VIII. Leucite-tephrite. Falkenberg, near Tetschen, Bohemia. R. Pfohl anal. Hibsch. Min. Pet. Mitth. Vol. XIV, p. 105, 1894.
IX. Leucite-nepheline-tephrite. Niedermendig, Laacher See. R. Mitcherlich anal. Zeit. deutsch. geol. Ges., Vol. XV, p. 374, 1863.
X. Monchiquite. Cabo Frio, Brazil. M. Hunter anal. Hunter and Rosenbusch. Min. Pet. Mitth., Vol. XI, p. 454, 1890.
XI. "Basalt." Table Mountain, Denver, Colorado. Eakins anal. Cross. Mon., XXVII U. S. Geol. Surv., p. 308, 1896.

As the original specimens were small, these differences cannot be ascribed to differences of composition in different parts of the mass, but are more probably due to the different analytical methods used. This applies especially to the alkalis; in the determination of which the usual German method of treatment of the rock with HF and $H_2 SO_4$, and subsequent separation of Al, Fe, Mg, and Ca, instead of the much more expeditious and accurate method of J. Lawrence Smith, tends to erroneous and discrepant results largely through contamination with alkalis derived from the glass vessels and reagents employed.

Having thus obtained an insight into the chemical and mineralogical composition of these rocks, it will be well to determine their place in the present scheme of classification.

In the first place, the very close correspondence of both my analyses, except in the minor constituents TiO_2 and P_2O_5, show that, in any scheme based on this character alone, they are to be classed together. Indeed, this is true of all the rocks of the Kula region examined by me, as shown by the analyses of Röhrig given in the original paper.

From a purely chemical standpoint it is abundantly evident that they are not to be referred to the basalts as this name is at present understood, since the alkalis are far too high for this group of rocks. The alumina is also too high, at least in comparison with the basalt analyses in which this constituent has been determined with proper care. Nor are they to be put with the subgroup of hornblende-basalts, as is shown by comparison with some typical analyses of these given in V, VI, and VII. The Kula rocks differ from these in having higher SiO_2, Al_2O_3 and alkalis, and lower iron oxides, MgO and CaO. In other words, they are more properly leucocratic, while the hornblende-basalts are melanocratic. At the same time the hornblende-basalt from Kosk Creek (VII), described by Diller, occupies a rather intermediate position between the Kula rocks and the typical hornblende-basalts of the Rhone and other regions.

The closest analogues of the Kula rocks are to be found among the nepheline-tephrites and nepheline-basanites. It is

true that many of these are markedly lower in SiO_2, Al_2O_3 and Na_2O, but at the same time analyses of these are to be found which closely resemble mine of the Kula rocks, as those of the nepheline-tephrite from the Falkenberg, near Tetschen, Bohemia, described by Hibsch (VIII), and the leucite-nepheline-tephrite of Niedermendig (IX).

They also resemble closely the monchiquites, as shown by a typical analysis of one of these (X), the main difference being in the higher content of H_2O in the monchiquites, consequent on their containing analcite in place of nepheline.[1]

Rocks which chemically closely resemble these are certain "basalts" from Colorado, described by Cross, an analysis of one of which is given in XI. These carry considerable orthoclase, but no nepheline, and with biotite instead of hornblende.

Turning to the mineralogical composition, it must be noted that most of the Kula rocks present a peculiarity which adds somewhat to the difficulty of classification. They have been spoken of as containing hornblende as an essential constituent. This is strictly true only of the more glassy varieties, in which basaltic hornblende is fresh and unaltered. In the others—including those analyzed—this mineral has been partially or entirely altered to hypersthene, diopside and magnetite, so that, speaking with strict accuracy as to their present composition the majority of them cannot be said to contain any hornblende at all.

This naturally raises the difficult question, whether the original hornblende should be recognized as a component. Of its initial presence, and the derivation of the hypersthenic and diopside-magnetite "mixed crystals" or pseudomorphs from it there can be absolutely no doubt, from the evidence of the shape of the pseudomorphs, the transitions to unaltered hornblende, and other facts observed here and elsewhere.

The case is strictly comparable with the occurrence of so-called "pseudo-leucites," mixtures of orthoclase and nepheline or muscovite, pseudomorphous after original leucite. As

[1] Cf. L. V. Pirsson: Jour. Geol., Vol. IV, p. 679, 1896.

rocks containing these are called "leucite-syenite," "leucite-eleolite-syenite" and "leucite-phonolite" by Rosenbusch and Zirkel, it would seem to be justifiable, at least for the present, to speak of the Kula rocks as hornblende-bearing.

The analyses I and III calculate out very sharply as shown in the table below, with results worth commenting on. In the

	I a	III a[1]
Anorthite	17.9	17.9
Albite	8.4	23.6
Orthoclase	23.4	..
Leucite	..	17.4
Nepheline	20.4	12.8
Diopside	12.8	13.8
Olivine	10.7	9.5
Magnetite	3.7	3.7
Apatite	1.8	..
Water, etc.	0.8	1.3
	99.9	100.0

first place this calculation confirms the observation that nephe line is present, as there is too much Na_2O or too little SiO_2 to satisfy each other on any other basis.

It is also of interest to note that, although these rocks are so basic in composition, and so basaltic in general habit and appearance, yet the feldspars and feldspathoids constitute over 70 per cent. of the mass, and that they consequently are leucocratic, to use the distinction into two groups recently given by Brögger.[2] So little is known of the rocks of Asia Minor that as yet no melanocratic complements of these are positively known, though it is to be expected that they will be discovered some time in this petrographic province.

It will be noticed that in I the plagioclase is a bytownite of the composition Ab An_4, while in II it is an andesine, approximately Ab_3 An_2. It is certainly remarkable that in the one

[1] Inasmuch as diopside, hornblende, hypersthene and olivine are present together in III, it is impossible to calculate the exact relative amounts of each, and the analysis has, therefore, been calculated on the assumption that only diopside and olivine are present. The error involved will not be large, as the hornblende tends to alter to a mixture of diopside and magnetite.

[2] BRÖGGER: Erupt. gest. d. Kristianiageb, III, p. 263, 1898.

rock orthoclase is associated with the lower SiO_2, as well as with a bytownite, while in the other leucite occurs with higher SiO_2 and lower K_2O, and with the plagioclase an andesine. In the latter also the albite molecule is higher and nepheline correspondingly lower, while the other constituents (except apatite) remain the same.

This is peculiar, but there seems to be no doubt of the facts, and the difference is possibly to be connected with differences in the conditions of solidification. The specimen of I came from a depth of thirty-five meters in a lava flow, possibly of Kula Devit, but more probably of an earlier volcano, while the leucite-kulaite was from the surface of a late flow of Kula Devit.

There would thus have been certain, even if slight, differences in pressure and rate of cooling, which might account for the difference in mineralogical composition. It has already been pointed out elsewhere[1] that these intermediate latitic magmas seem to be in a nicely balanced state of chemical equilibrium which only need very slight differences in conditions of solidification to result in quite diverse mineralogical aggregates. The facts here are also in accordance with the general observation that leucite is essentially a mineral of the effusive rocks, while orthoclase occurs in either intrusive or effusive masses, this tendency toward the formation of leucite in flows in contradistinction to the formation of orthoclase in domal eruptions being especially well seen along the main line of Italian volcanoes.[2]

We have already seen that the analyses correspond most nearly with those of the tephrites. Accepting, however, the general definition of a tephrite as an effusive rock composed essentially of plagioclase and nepheline or leucite, with pyroxene or other ferromagnesian components, it is very clear that the rock represented by analysis I, which contains 23 per cent. of orthoclase, cannot properly be put in this group. Indeed,

[1] H. S. Washington: Jour. Geol, Vol. V, p. 376, 1897.
F. L. Ransome: Amer. Jour. Sci., Vol. V, p. 370, 1898.

[2] Cf. Jour. Geol., Vol. V, p. 376, 1897.

the calculated mineral composition, yielding 23.4 per cent. of orthoclase and 26.3 of plagioclase, is fully corroborative of the position to which Rosenbusch assigns this rock, among the latites or trachydolerites.

It would seem, then, advisable, as well as justifiable, to reserve the name "kulaite" to denote a basic rock of the series of latites (Rosenbusch's trachydolerites), in which orthoclase and lime-soda feldspar are present in about equal amounts, together making up half the rock, with nepheline to the extent of from 12.5 to 25 per cent. The ferromagnesian constituent is typically hornblende or pseudo-hornblende, and diopside and olivine are also present. These rocks, though low in silica, are essentially leucocratic in character.

The case of the "leucite-kulaites" is rather different. On the basis of chemical composition and genetic association they would naturally be classed with the kulaites, as varieties of these in which leucite replaces orthoclase. At the same time, composed as they are of plagioclase, nepheline and leucite, with ferromagnesian minerals, they are perfectly covered by the tephrites, and in the present schemes must be called leucite-nepheline tephrite.

I have gone at some length into the question of the position and names of these rocks, not because the matter is of any great importance in itself, but because they serve very well to exemplify the difficulties and complexities of our present methods of classification. It is the old story of magmas of identical chemical compositions solidifying as different mineral aggregates. With the rapid increase in our knowledge of rocks, and especially through more numerous analyses and their more careful execution, examples of this are becoming of quite frequent occurrence in petrographical literature. Most cases, as those of venanzite and madupite, the minette or selagite of Monte Catini and wyomingite, and many more, are of rocks from widely distant parts of the globe.

Here, however, there are found at one small center recent flows which must be referred to the distinct groups of basic

latites, leucite-tephrites and, to include the tachylitic varieties described in the original papers, hornblende-limburgites. These rocks which, according to the principles of classification at present in vogue, we must place in such diverse and distant parts of our scheme, are all products of one center of eruption, parts of the same undifferentiated magma, identical in chemical, and in many points of mineralogical, composition. A rational or natural scheme of classification should express their evident close relationship, but on account of somewhat diverse mineralogical composition, due to such extraneous and accidental causes as conditions of cooling and the like, their mutual affinities are to a large extent masked by the diverse names which must be given them.

We are brought face to face with the question, whether we should hold to the present system, based on structure and (largely qualitative) mineral composition; or whether we should strive to base our classification primarily on the most fundamental character of igneous rocks—their chemical composition, the quantitative mineral composition being a function and an exponent of this.

The choice of the latter would certainly seem to be justified on sound theoretical grounds, and has been advocated by Pirsson,[1] Iddings,[2] Brögger,[3] Loewinson-Lessing,[4] and others. It is, of course, also well known that Brögger holds that genetic relationships should find expression in classification; in other words, that the system of classification should be not a Linnean but a natural one. But discussion of this and kindred topics would carry us far beyond the limits of this paper.

That any change will present difficulties of a practical as well as of a theoretical nature is obvious. The aid of chemical analysis, as well as of the microscope, must be invoked much more often than in the past, though with increasing knowledge

[1] PIRSSON, Amer. Jour. Sci., Vol. L, p. 478, 1895.

[2] IDDINGS, JOUR. GEOL., Vol. VI, p. 103, 1898.

[3] BRÖGGER, Amer. Jour. Sci., Vol. IX, p. 458, 1900.

[4] LOEWINSON-LESSING, Compt. Rend., VII, Cong. Geol. Int., 1897, pp. 193–464.

this would be less vital in many cases than may be thought by some. Cases of uncertainty as to the position and relationships of a particular rock will occur, but presumably less frequently than under the present system. These and other difficulties will have to be met and overcome. But, as Iddings, Brögger, and others have urged, the time is at hand for a revision and change of our whole system of classification and subsequently of nomenclature, and it is well to remember the general truth of the saying, "*C'est le premier pas qui coûte.*"

HENRY S. WASHINGTON.

SUCCESSION AND RELATION OF LAVAS IN THE GREAT BASIN REGION[1]

RICHTHOFEN'S STUDIES

THE Great Basin was early recognized as showing a variety of Tertiary lavas which are identical over large areas, and erupted in somewhat the same succession. The first deductive studies from these facts were made by the Baron von Richthofen,[2] and were published in 1867. Partly as a result of observations in the rocks of the Great Basin and of California, and partly from studies in the volcanic regions of Europe, Richthofen arrived at what he considered to be the natural law for the sequence of massive eruptions, applicable to all centers of volcanic activity. According to him the order of succession was:

1. Propylite.
2. Andesite.
3. Trachyte.
4. Rhyolite.
5. Basalt.

This law of succession was accepted without much question for a long time by many European and American geologists.

THEORIES OF THE ORIGIN OF IGNEOUS ROCK DIFFERENCES PREVIOUS TO RICHTHOFEN[3]

By way of summarizing briefly the difference between Richthofen's theories and those of his predecessors, it may be remarked that Bunsen, who was one of the first to speculate concerning rock differences, after visiting Iceland and studying the volcanic phenomena, formed the hypothesis of two distinct magmas or bodies of lavas, one acid, and the other basic; the normal "trachytic" and the normal "pyroxenic" magmas,

[1] Published by permission of the Director of the United States Geological Survey.

[2] "Natural System of Volcanic Rocks," Mem. California Acad. Sci., Vol. I, p. 36.

[3] See Monograph XX, U. S. Geol. Surv., p. 273.

as he called them. He regarded all lavas between these extreme types as mixtures of the two in varying proportions. It will be noted that Bunsen's explanation[1] was essentially a theory of mixing rather than of differentiation.

Durocher[2] accepted Bunsen's idea of the existence of an acid and a basic magma, and admitted the possibility of a mingling of the two in certain cases to produce intermediate types, but did not follow this idea to the extent of Bunsen. Durocher proposed the hypothesis, which was not substantiated by much study of volcanic action in the field, that certain lavas may be produced by segregation, or differentiation, *i. e.*, by the breaking up of a magma into several different parts, as a result of chemical activity. Durocher's ideas of the origin of igneous rocks, therefore, include the idea of segregation, or differentiation, together with that of mixing.

Roth[3] later also held that a magma may segregate during crystallization into lavas of different mineralogical composition, although his ideas of the processes of differentiation were not specifically identical with those of Durocher, who had considered these processes analogous with those by which metals are segregated in metallurgical operations.

Von Waltershausen,[4] after studying the lavas of Sicily and Iceland, came to the conclusion that lavas were derived from a zone of molten material between the earth's crust and its solid interior, and that the material arranged itself according to the laws of gravitation, so that the most siliceous lava, which is also the lightest, was nearest the surface; the most basic at the bottom, and the intermediate lavas in the zones between. His own observations in the field seemed to point out that the lavas were

[1] Ueber die Processe der vulkanischen Gesteinsbildung Islands, Poggendorf's Annalen, 1851, Band 83, pp. 197–272.

[2] Essai de Pétrologie comparée, Ann. d. Mines, Paris, 5th series, 1857, Tome XI, pp. 217–259.

[3] Tabellarische Uebersicht der Geistens-Analysen, mit kritischen Erläuterungen, Berlin, 1861.

[4] Ueber die vulkanischen Gesteine in Sicilien und Island und ihre submarine Umbildung, Göttingen, 1853.

thrown out according to their supposed superposition, the order being, therefore, regularly from acid to basic lavas.

KING'S WORK AND ITS LATER MODIFICATIONS

The first careful work on the lavas of the Great Basin was done during the 40th Parallel Survey, the field-work of which was done chiefly by Messrs. Hague and Emmons, while the petrographic work was by Professor Zirkel, and the general results and deductions were made by the director, Mr. Clarence King.[1] Mr. King accepted in general the law of succession of volcanic rocks, as laid down by Richthofen, but subdivided the lavas of each member of the succession, and united the fourth and fifth members — the rhyolite and basalt[2] — under a general term, "Neolite." The natural order, as interpreted by King, was as follows:

Order	Subdivision
1. Propylite	*a.* Hornblende propylite. *b.* Quartz propylite. *c.* Augite propylite.
2. Andesite	*a.* Hornblende andesite. *b.* Quartz andesite (Dacite). *c.* Augite trachyte.
3. Trachyte	*a.* Hornblende-plagioclase trachyte. *b.* Sanidine trachyte (quartziferous). *c.* Augite trachyte.
4. Neolite	*a.* Rhyolite. *b.* Basalt.

As regards the laws maintained by Richthofen and King for the Great Basin, it is necessary to observe first of all that the first member — propylite — was proved by Mr. George F. Becker[3] to be simply a decomposed phase of the andesite in the Washoe district, instead of a separate rock, as supposed by Richthofen

[1] Geological Explorations of the 40th Parallel, Vol. I, p. 545 et seq.

[2] This colligation of rhyolite and basalt was made by King on the basis of their close association in the field. His explanations of this fact, however, were essentially different from later ones, now generally accepted, and first advanced by Mr. Hague, Mon. XX, U. S. Geol. Surv.

[3] Geology of the Comstock Lode, Washoe District, Mon. III, U. S. Geol. Surv., p. 88.

This conclusion was corroborated by subsequent investigators in different parts of the world, so that the term has passed out of use. It has also been proved by Mr. Becker's studies, and later by those of Messrs. Hague and Iddings,[1] that the trachytes of Richthofen and of the 40th Parallel Survey, as determined by Zirkel, are mainly andesites — in part hornblende-mica andesite, and in part hypersthene-augite andesite (the latter rock corresponding more nearly to the augite-trachyte of Zirkel), while a smaller proportion are dacites, and some are probably rhyolites. It has been determined by these investigators that trachyte is conspicuously absent in the province of the Great Basin. The reason for Zirkel's false classification was the lack of means at that time to determine the feldspars, so that the plagioclases were determined as sanidine, since they showed little or no striation.

SUCCESSION OF LAVAS PREVIOUSLY DESCRIBED IN THE GREAT BASIN AND VICINITY

Eureka district.— In the course of a careful study of the volcanic rocks of the Eureka district in Nevada, Mr. Hague[2] arrived at the following succession of lavas at this center of volcanic activity:

1. Hornblende andesite.
2. Hornblende-mica andesite.
3. Dacite.
4. Rhyolite.
5. Pyroxene andesite.
6. Basalt.

Washoe district.— In the Comstock or Washoe district, at the southern end of the Virginia Range, Mr. Becker[3] found the following succession of igneous rocks:

1. Granite.
2. Diorite.
3. Quartz-porphyry.

[1] "Volcanic Rocks of the Great Basin," Amer. Jour. Sci., June 1884, p. 453. Geology of the Eureka District, Mont. XX, U. S. Geol. Surv., p. 230 et seq.

[2] Mon. XX, U. S. Geol. Surv., p. 290. [3] Mon. III, U. S. Geol. Surv., p. 380.

4. Earlier diabase.
5. Later diabase.
6. Earlier hornblende andesite.
7. Augite andesite.
8. Later hornblende andesite.
9. Basalt

Messrs. Hague and Iddings,[1] after a careful microscopic study of the collections made by Mr. Becker in the Comstock region, arrived at somewhat different conclusions, although agreeing with Mr. Becker as to the identity of propylite with andesite. They concluded that the granular diorite and diabase, and the augite andesite, were variations of the same body, the granular rocks representing textural differences brought on by slowly cooling in the deeper parts of the extruded mass, while the finer-grained porphyritic rocks represented the periphery of the same. To substantiate their conclusion they show the existence of all possible gradations between the extreme types. They also conclude that the porphyritic diorite is identical with the hornblende andesite, and the mica diorite with the later hornblende andesite, the difference in each case being due to variations of texture. The quartz-porphyry of Mr. Becker they regard as partly dacite, and partly rhyolite; while the later diabase, or "black dike," they regard as identical with the effusive basalt. They find, also, that the pyroxene and hornblende andesites are difficult to separate, but that these are cut through by hornblende andesites, dacites, rhyolites, and basalts. The succession of lavas in this district is, according to Mr. Hague:

1. Pyroxene-hornblende andesite (inner portions pyroxene-hornblende diorite porphyry, and pyroxene-hornblende diorite).
   Period of volcanic rest and denudation.
2. Hornblende-mica andesite.
3. Dacite.
4. Rhyolite.
5. Pyroxene andesite.[2]
6. Basalt.

[1] "On the Development of Crystallization in the Igneous Rocks of Washoe," Bull. 17, U. S. Geol. Surv.

[2] See Mon. XX, U. S. Geol. Surv., p. 281. Compare the succession in the adjacent Pine Nut Range, p. 628.

The hornblende andesite of Eureka is correlated with the hornblende-mica andesite of Washoe, while the pyroxene-hornblende andesite of Washoe is supposed to belong to an earlier period, not represented at Eureka; otherwise the succession of lavas at the two centers of eruption is considered to be similar and the different extrusions in general contemporaneous.

Sierra Nevada.—Mr. H. W. Turner[1] published in 1895 a résumé of the age and succession of igneous rocks in the Sierra Nevada. According to him the succession of the Tertiary volcanics in this region is as follows:

1. Acid - - - -	Rhyolite—massive and fragmental.
2. Basic - - -	Older basalt—always (?) massive.
3. Intermediate - -	Hornblende-pyroxene andesite—chiefly tuff and breccia.
4. Intermediate to acid -	Fine-grained pyroxene andesites—massive
5. Basic - - - -	Doleritic basalts—massive.
6. Basic - - -	Other basalts—massive.

In 1898 Mr. F. L. Ransome[2] published a critical study of a portion of the western slope of the Sierra Nevada, in the Sonora and Big Trees region—a locality, it may be noted, much nearer to the Washoe district than the Washoe is to Eureka. Mr. Ransome succeeded in classifying more accurately than had hitherto been done some of the intermediate lavas, determining rocks that had previously been classified variously as basalts, trachytes and andesites as belonging to the monzonitic family, intermediate between the granitic and dioritic families. For the volcanic variety of monzonite he proposed the term "latite." The succession of the Tertiary lavas in the region studied by Mr. Ransome is as follows:

1. Biotite rhyolite.
   Rhyolite tuffs.
2. Olivine-basalt.
3. Hornblende-pyroxene andesite brecca.

[1] JOUR. GEOL., Vol. III, No. 4, May–June 1895.

[2] Bull. 89, U. S. Geol. Surv. Also Amer. Jour. Sci., May 1898, 4th series, Vol. V, p. 355.

4. Latite { Augite-biotite hornblende latite.
   Biotite-augite latite.
5. Hornblende-pyroxene andesite breccia.
6. Olivine-basalt.

Tintic district.— Passing from the Sierra Nevada and the western border of the Great Basin (from the Sonora region and the Washoe district) eastward past Eureka, we will next cite the record of Tertiary vulcanism in the Tintic Range, which lies south of Salt Lake and southwest of Utah Lake, and is approximately the same distance from Eureka as Eureka is from Washoe. This region has been studied by Messrs. Tower and Smith.[1] The succession of lavas is as follows:

1. Biotite rhyolite.
2. Pyroxene-hornblende-biotite andesite — tuffs and breccias.
3. Pyroxene-hornblende andesite (latite).
4. Olivine-basalt.

The rhyolitic flows of the first member of the succession given above are known to be continuous and contemporaneous with dikes of rhyolite which, on account of their somewhat different habit, were given the name of *quartz-porphyry* in the text. This intrusive rhyolite appears to be susceptible of correlation with the rhyolite or "quartz-porphyry," described by the writer,[2] from the northern end of the Oquirrh Range, which lies south of the Tintic district (Eagle Hill porphyry). The rhyolite in the Tintic district is known to be later than Upper Eocene.

The pyroxene-hornblende andesites (or latites) described by Messrs. Tower and Smith are regarded by them as belonging to the same general body as certain large masses of granular monzonite with which they are connected by transitional phases; the monzonite representing portions of the magma which have consolidated as intrusive masses under conditions favoring better crystallization than those under which the extrusive sheets of pyroxene andesite (or latite) have consolidated. These

[1] "Geology and Mining Industry of the Tintic District, Utah," Nineteenth Annual Rept. U. S. Geol. Surv., Part III, Economic Geol., p. 632.

[2] J. E. Spurr, "Economic Geology of the Mercur Mining District," Sixteenth Ann. Rept., Part II, p. 377.

transitions from typical fine-grained extrusives to porphyritic and to coarse granular intrusive rocks are highly interesting in themselves and by comparison with the similar phenomena which Messrs. Hague and Iddings[1] have found in the andesite and basalts of the Washoe district. The present writer has also found similar transitions, to be described elsewhere.

SUCCESSION OF LAVAS AT OTHER POINTS IN THE GREAT BASINS

During the past season's field work the writer has observed the succession of lavas at many different points in the Great Basin. From the nature of the work the time for study was in each case very restricted, so that the records given below are sometimes very likely incomplete.

Pine Nut Range.—The Pine Nut Range is interesting on account of lying immediately south of the Virginia Range and the Washoe district, and because the lavas of this district are easily recognizable in it. The range was crossed at two points, one east from Dayton and one east from Genoa. The succession of lavas appears to be as follows:

1. Rhyolite (intimately connected and probably contemporaneous with granite of similar constitution).
   Rhyolite sands and conglomerates (formed during long period of erosion).
2. Hornblende-pyroxene-biotite andesite (in portions sufficiently removed from the surface the typical glassy or microcrystalline groundmass of the lava becomes coarser, leading to the formation of diorite porphyry and monzonite porphyry).
3. Hornblende-mica andesite.
   Period of denudation.
4. Rhyolite (Shoshone Lake period?).
5. Hornblende-pyroxene andesite, tuffs, and breccias (Shoshone Lake period).
6. Rhyolite.
7. Basalt (Pleistocene).

Of these extrusives the first appears to have been greatest in amount and the latter ones in general progressively less and less, in the order of their arrival.

[1] Bull. 17, U. S. Geol. Surv.

Sweetwater Range.—The Sweetwater Range may next be considered, since it lies south of the Pine Nut Range and shows very nearly the same rocks. It is separated from the Pine Nut Range only by the Walker River Valley, while at its southern end it connects with the Sierras, of which it may thus be considered a spur.

The observed succession of lavas in this range is as follows:

1. Rhyolite (closely connected and perhaps contemporaneous with granites of similar composition).
2. Hornblende-pyroxene andesite.

   Epoch of erosion and subsequent formation of Shoshone Lake.
3. Hornblende-pyroxene andesite, tuffs and breccias.
4. Hornblende-biotite latite.
5. Basalt.

Gabb's Valley Range.—In the lavas of Gabb's Valley and the Gabb's Valley Range, which lies just east of Walker Lake, the following succession was made out:

1. Biotite andesite.
2. Biotite rhyolite.
3. Hypersthene-hornblende aleutite.[1]
4. Augite basalt.

A granular rock, which had every appearance of being effusive, was also found in Gabb's Valley, and on examination proved to be a hornblende-biotite quartz-monzonite. This, however, is not included in the list, since its exact position is uncertain. It is very likely earlier than all the others and is perhaps contemporaneous with the biotite-hornblende quartz-monzonite, which forms the oldest rock in the Walker River Range, being more ancient than the granite.

Silver Peak Mountains.—Mr. H. W. Turner, who has studied the volcanic record in the Silver Peak district, has kindly supplied the writer with the preliminary statement that in general the succession of lavas here is as follows:

1. Rhyolite.
2. Andesite.
3. Basalt.

[1] See American Geologist, April 1900, p. 230.

Ralston Desert.—According to observations made by the writer, the succession of lavas in the Ralston Desert is as follows:

1. Rhyolite and tordrillite[1] (earlier).
2. Rhyolites, often glassy (late Pliocene).
3. Olivine-basalt (Pleistocene).

Practically the same succession is seen in the Kawich Range and in the Reveille Range.

Lake Mono Basin.[2]—In the basin of Lake Mono, according to Professor Russell, we have extensive Pleistocene volcanic activity, the lavas being basalt, hypersthene andesite verging on basalt, and rhyolite. Older than these is a hornblende andesite. The succession in this basin is, then:

1. Hornblende andesite.
2. Basalt, hypersthene andesite verging on basalt, rhyolite.

The relative age of the lavas under 2 was not determined, but they are all regarded as Pleistocene.

Toyabe Range.—In the southern end of the Toyabe Range the known succession of Tertiary lavas is as follows:

1. Biotite rhyolite (closely associated and perhaps contemporaneous with intrusive biotite granite).
2. Augite basalt (Pleistocene).

Schell Creek Range.—In the Schell Creek Range, near Schellbourne, we have the following succession of lavas:

1. Biotite rhyolite (flows often glassy).
2. Pyroxene aleutite (probably late Pliocene).

Egan Range.—In the Egan Range the following lavas were found:

1. Dacite-andesite.
2. Basalt.

Meadow Valley Canyon.—In the Meadow Valley Canyon (southward from Pioche) we have one of the best exposures of Tertiary lavas and their associated sediments which has yet been

[1] See Classification of Igneous Rocks according to Composition, J. E. Spurr, Am. Geol., April 1900, p. 230.

[2] Quaternary History of Mono Valley, California; Eighth Ann. Rept. U. S. Geol. Surv., Part I, p. 374, 379, etc.

found in Nevada. The completeness of the section enables one to see how complicated the history of Tertiary vulcanism and sedimentation is, but the following is the general succession:

1. Biotite rhyolite.
   Rhyolite tuffs and sands.
2. Pyroxene andesite, tuffs and breccias.
   Biotite-hornblende quartz-latite (basic).
   Biotite-hornblende dacite.
   Biotite-hornblende rhyolite, and tordrillite (heavy flows).
   Thin-bedded rhyolite (Pliocene).
3. Pyroxene olivine-basalt.
   Rhyolite-tordrillite. (Pleistocene.)

Funeral Range.—The volcanic activity of the Funeral Range has not been very well observed, but the following is part at least of the succession:

1. Biotite andesite (Eocene or Miocene).
2. Olivine-basalt.

Panamint Range.—In the Panamint Range the following succession of lavas has been observed:

1. Feldspathic lavas of medium acidity; species undetermined.
   Rhyolite.
2. Andesite (late Eocene or Miocene).
3. Pyroxene aleutites and basalts, often olivine-bearing (late Pliocene or Pleistocene).

Randsburg region.—In the mountains in the vicinity of the mining camp of Randsburg, in southern California, the writer observed the following succession:

1. Biotite rhyolite (early Eocene?).
   Rhyolitic tuffs and sands.
2. Hornblende-pyroxene-biotite aleutite.
3. Pyroxene basalt
   Pyroxene olivine-diabase porphyry (dike). (Pleistocene.)

Coso Range.—According to Mr. Fairbanks,[1] the following is the succession of lavas in this range, roughly stated:

1. Rhyolites and andesites.
2. Basalts.

[1] Am. Geol., Vol. XVI, February 1896, p. 73.

Daggett or Calico region.—Southward, in the middle of the Mojave Desert, at Daggett, or Calico (which is on the Mojave River and also on the Santa Fé Railway), great masses of rhyolite have been described,[1] underlying the borax-bearing lake beds which are probably, in part at least, Upper Eocene. These rhyolites are plainly the same as those in the Coso Range and in the Randsburg region.

SUCCESSION OF LAVAS IN THE GREAT BASIN REGION IN GENERAL

In the field it is evident that the same lavas occur in many different localities throughout the Great Basin region, in much the same relative quantity, having nearly the same mineralogical composition, and giving evidence of about the same relative age. Moreover, where two or more of these lavas are found close together, their order of succession is found to be in general nearly the same, although at any given place certain members of the series may be lacking. In no single locality has the complete succession, as indicated by the correlation of all the different sections, been observed; but in order to find it we may fill gaps in one place from the observations in another. In correlating similar lavas erupted at different points, we must consider not only the succession but the relative age of each, so far as this is known. The evidence of this age will be briefly outlined later on; it is with this in mind, however, that the following table has been made. Many of the correlations are only provisional, and will probably require adjustment and rearrangement as the result of future investigation; but it is believed that the general deductions are correct.

By this correlation we see that the succession of lavas seems to have been roughly uniform over the whole region, although minor variations have been numerous at many points. In general, it appears possible to divide the lavas into five groups, in the order of their eruption, as follows:

1. Acid (type, biotite rhyolite).
2. Siliceous intermediate (medium andesites).

[1] W. H. STORMS: Eleventh Rept. State Mineralogist California, p. 347. Sacramento, 1893.

3. Acid (rhyolites with composition like 1) with occasional connected basalts.
4. Basic intermediate (more basic andesites and aleutites).
5. Basic (basic basalts), frequently with closely connected rhyolites.

CORRELATION OF LAVA GROUPS IN POINT OF AGE

The absolute age of the different Tertiary lavas is not easy to find out, although in many special cases it may be done with a fair degree of accuracy. The most recent eruptions are naturally the most easy of determination, while those more remote are more obscure.

1. *Acid.*—In the Pine Nut and Sweetwater ranges the definite age of the older rhyolites is uncertain, but they are separated from the great bodies of massive hornblende-pyroxene-biotite andesite, which itself antedates the Pliocene Shoshone Lake, by a long period of erosion. These rhyolites are also affected by a sheeting which is not found in the andesites, and which indicates crustal disturbance between the eruption of the two lavas.

The observations concerning the Pine Nut and Sweetwater ranges are in general true, also, for the Reveille, Quinn Canyon, and Grant ranges.

In Meadow Valley Canyon the basal rhyolite, with its overlying tuffs, is folded and separated by a marked unconformity from the andesitic lavas and tuffs which succeed. The rhyolite tuffs are roughly estimated at 4000 feet thick, and mark a long period of Tertiary sedimentation, which intervened between the rhyolites and the andesites.

In the Silver Peak region rhyolites are interbedded in portions of the Tertiary lake sediments, which are probably late Eocene or early Miocene.[1]

In the Panamint Range, in the Randsburg district, and near Daggett in the Mojave Desert, lake beds which are probably in part at least Upper Eocene overlie the basal rhyolite.

In general, therefore, it may be said that the age of the rhyolite, which is the first member of the general succession,

[1] H. W. TURNER: The Esmeralda Formation. Am. Geol., Vol. XXX, March 1900, p. 168.

varies in different portions of the petrographic province from early to late Eocene. Strict contemporaneity is not to be expected, but only broad correspondence.

2. *Siliceous intermediate.*—In the region of the 40th Parallel Survey, Mr. King[1] considered that the beginning of Miocene time came between the main period of the hornblende andesites (No. 2 of the succession here outlined) and that of the augite andesites (No. 4 of this succession). Mr. King found his Miocene beds (sediments of the Pah-Ute Lake) largely made up of tuffs derived from what was at that time regarded as trachyte, and he therefore considered the trachytic period as Miocene. The trachytes of the 40th Parallel Survey have been shown to be mainly andesites, in part hornblende-mica andesites and in part pyroxene andesites.[2]

In the Virginia, Pine Nut and Sweetwater ranges, the hornblende-pyroxene-biotite andesites were erupted and eroded previous to the formation of the Shoshone Lake, to which they formed the shores. The Shoshone Lake probably existed in late Pliocene and earliest Pleistocene time; this puts back the age of these andesites to at least early Pliocene.

In the Silver Peak region andesites occur, together with abundant andesitic tuffs, in portions of the Esmeralda formation, which is probably late Eocene or early Miocene.

In the El Paso Range, according to Fairbanks, andesite occurs as interstratified sheets in the late sediments of the Upper Eocene.

Taken altogether, it may be said that the period of eruption of the medium-siliceous andesitic lavas was chiefly in the Miocene, although it probably ran back to the Upper Eocene. The periods of eruption No. 1 and No. 2 therefore overlap, and they are actually found close together in certain of the Upper Eocene lake sediments.

Acid.—Concerning the age of the third member of the succession there are somewhat better data. In the 40th Parallel

[1] Explorations of the 40th Parallel, Vol. I, p. 692.

[2] HAGUE and IDDINGS: Volcanic Rocks of the Great Basin. Am. Jour. Sci., 3d series, Vol. XXVII, January 1884, p. 456.

region Mr. King[1] notes that the rhyolites and rhyolite tuffs seem to be Pliocene. In the Eureka district Mr. Hague[2] came to the same conclusion as regards the rhyolite there.

In western Nevada rhyolities are found interbedded and therefore contemporaneous with the sediments of the late Pliocene Shoshone Lake in a number of localities, as, for example, on the borders of the Pine Nut Range. The same relation to the Shoshone Lake beds was noted on the western edge of the Ralston Desert.

In the mountains near Candelaria glassy rhyolite overlies the folded Upper Eocene or Lower Miocene of the Esmeralda formation. The folding which has affected these beds is the same as that which has upturned the Miocene further north, called by King the Truckee Miocene; so the disturbance must have been late Miocene or post-Miocene. The rhyolite in this case, therefore, is probably as young as the Pliocene.

In the Sierra Nevada Mr. Turner[3] referred the rhyolites to the Upper Miocene. According to Mr. Lindgren[4] the rhyolitic flows of the Sierra in the Truckee region began "toward the close of the Miocene."[5]

In general, therefore, the age of the second chief rhyolite eruption ranges from late Miocene well into the Pliocene.

Basic intermediate. — In the Sierra Nevada, according to Turner,[6] the pyroxene andesite is Pliocene.

[1] Explorations of the 40th Parallel, Vol. I, p. 694.

[2] Mon. U. S. Geol. Surv., Vol. XX, p. 232.

[3] Igneous Rocks of the Sierra Nevada, JOUR. GEOL., Vol. III, No. 4, May-June 1895, p. 406; Auriferous Gravels of the Sierra Nevada, Am. Geol., June 1895, p. 372.

[4] Truckee folio, U. S. Geol. Surv., p. 3.

[5] The writer was at first inclined to correlate the rhyolite of the Sierra Nevada with the earliest rhyolite shown in the general correlation table (No. 1 of the general succession); but a number of considerations, among others that of the comparatively slight age of the Sierra Nevada rocks, as given above, induced him to class them with later rhyolites (No. 3 of the general succession). In agreement with this conclusion are Hague's views (Mon. XX, U. S. Geol. Surv., pp. 261, 281.

[6] Age and succession of the Igneous Rocks of the Sierra Nevada, JOUR. GEOL., Vol. III, June 1895, p. 408.

In the Sweetwater Range, near Wellington, pyroxene andesite flows are found intercalated with the sediments of the great Pliocene Shoshone Lake.

In the Schell Creek, Antelope, and Snake ranges the pyroxene aleutite, which overlies glassy biotite rhyolite, has filled up valleys which are probably early Pliocene, and has suffered only slight erosion, resulting in the development of a narrow Pleistocene valley, since that time. It can hardly, therefore, be older than late Pliocene.

On the whole the main period of eruption of the basic intermediate lavas appears to have been during the Pliocene, and chiefly the late Pliocene. Most of the great andesitic breccias, indicating widely distributed explosive eruptions, seem to belong to this period.

5. *Basic.*—In the Eureka district it is suggested that the latest outbursts, which were of olivine-basalt, occurred in the Pleistocene.[1]

Near Steamboat Springs, which is just west of the southern end of the Virginia Range and in the immediate district of the Comstock lode, the writer observed that the olivine-basalt is probably early Pleistocene, since it has filled the valleys and covered the scarps eroded by the late Pliocene and early Pleistocene Shoshone Lake.

On the borders of the Pine Nut Range the basalt appeared after the Shoshone Lake had shrunk to the later Pleistocene Lake, and after the country exposed by this recession had been partly dissected into canyons. It is therefore plainly of Pleistocene age.

In the Ralston Desert and in the Reveille and Pancake ranges the basalt overlies the Pliocene sediments, supposed to belong to the Shoshone Lake period. In the Quinn Canyon and Grant ranges the basalt has been poured out into valleys which were probably formed in the late Pliocene period.

In most of the other localities where this lava has been found there is little doubt that the age is Pleistocene, although some of the eruptions may date back to the late Pliocene.

[1] Mon. U. S. Geol. Surv., Vol. XX, p. 232.

TABULATION

The relative age of the different members of the volcanic section, therefore, may be roughly outlined in the following table. It must be remembered that this is only approximate.

The age of the members of volcanic succession being determined, we can sometimes apply this determination in cases where the age of the lavas cannot be independently ascertained, and use them roughly as time markers.

Epochs of sedimentation	Standard time divisions	Epochs of vulcanism
	End of Cretaceous	No. 1. Acid (type, biotite rhyolite)
Eocene-Miocene Lakes	Eocene	
	Miocene	No. 2. Medium intermediate (type, hornblende-mica-pyroxene andesite)
		No. 3. Acid (type, biotite rhyolite)
Shooshne Lake	Pliocene	No. 4. Basic intermediate (types, pyroxene, andesite, etc.)
Lake Lahontan	Pleistocene	No. 5. Basic and acid (basalts and occasional rhyolites)
Walker Lake, etc.		

LAW OF SUCCESSION OF LAVAS

The most natural deduction from all these harmonious observations is that the Great Basin, southward into the Mojave Desert, together with a portion at least of the Sierra Nevada, constitutes a petrographic province; that is to say, it is underlain by a single body of molten magma, which has supplied, at different periods, lavas of similar composition to all the different parts of the overlying surface. The limits of this subcrustal basin, however, are not yet defined in any direction.

In studying the eruption of different lavas from this magma basin at different periods, it is instructive to inquire whether or not the succession follows any definite laws. Mr. Iddings[1] interpreted the usual law of succession in volcanic rocks as this: that a series begins with a rock of average composition, and passes through less siliceous and more siliceous ones to rocks extremely high in silica and others extremely low in silica—that is, the series commences with a mean and ends with extremes. This interpretation of Iddings was based on his work in the Yellowstone Park and vicinity, at Eureka, Washoe, and elsewhere. From studies of the eruptive rocks in the vicinity of Christiania Professor Brögger also thought to have determined a definite law of succession, by which the lavas progress from the most basic to the most acid varieties. Sir Archibald Geikie,[2] from a study of igneous rocks in Great Britain, has come to the same general conclusion as to the succession.

The section of Tertiary volcanics exposed at Eureka and Washoe, as given by Mr. Hague, begins with what is designated by the present writer No. 2 in the succession, and does not reach back to the basal biotite rhyolite. The general succession for the Great Basin, leaving out this basal rhyolite, appears, then, to be as follows:

2. Siliceous intermediate.
3. Acid (and basic).
4. Basic intermediate.
5. Basic (and acid).

[1] The origin of igneous rocks, Bull. Phil. Soc. Washington, Vol. XII, p. 145.

[2] Quar. Jour. Geol. Soc. Lond., 1892, Vol. XLVIII, p. 177.

Under No. 5 we find the very basic olivine-basalts and very siliceous rhyolites or tordrillites, erupted at the same period and evidently connected by the closest ties. This, for example, was observed to be the case in the Pleistocene volcanics of the Meadow Valley Canyon, and the same is true in the basin of Lake Mono, according to Russell.[1]

These closely allied ultra-basic and ultra-acid lavas are plainly complementary forms, and are proofs of differentiation as convincing as are the complementary segregations so familiar in single masses of intrusive or plutonic rocks.

Going a little further, if we write Nos. 3 and 4 of this last succession together and precede it by No. 2 (which we may divide into two members) we have the following grouping:

2. { Medium andesite.
   { Acid andesite and dacite.

3. { Acid rhyolite (with basalt).
4. { Medium basic andesite.

5. { Basalt.
   { Acid rhyolite.

We have here, therefore, a series (apparently conformable to Iddings' law) which begins with a rock of intermediate composition and progresses to extremes, as a result, probably, of differentiation.

But the first member in the order of succession as interpreted by the writer, viz., the basal rhyolite, is apparently out of place in this scheme. This rock has a composition essentially like the later rhyolite, but appears to have no immediate connection, mineralogically or chemically, with the andesites which form the base of the Eureka lavas. The andesites can hardly be derived from the rhyolites by any hypothetical differentiation, and even in that case the order seems in direct opposition to all of the hitherto propounded laws of succession.

It was first, therefore, the conclusion of the writer that the law deduced by Iddings would not hold good in the Great Basin, on

[1] Quaternary history of Mono Valley, California: Eighth Ann. Rept. U. S. Geol. Surv., Part I.

account of the basal rhyolite. From further study, however, the evidence of differentiation up to this point appears to be so good that he is inclined to accept it, and to consider the basal rhyolite as belonging to a different order of events.

This basal rhyolite is, in chemical and mineralogical composition, much like the latest rhyolite, No. 5, in the writer's order of succession. Like it, it often becomes extremely siliceous. From this circumstance, and from the apparent break in composition between the rhyolite No. 1 and the andesite No. 2, the writer conceived the idea that the two rhyolites are *recurrent* lavas—that is, that they represent a similar development in distinct but similar processes of differentiation. The development of lavas might then be interpreted as follows:

1. Acid rhyolite.
   Revolution and beginning of new epoch.
2. Medium to acid andesite and dacite.
3. Acid rhyolite (with basalt).
4. Medium basic andesite.
5. { Basic basalt.
   { Acid rhyolite.

In case this is the current grouping, it is probable that No. 1 represents the end product of a differentiation, and is similar to the rhyolite under No. 5; and that 2 to 5 inclusive represent an independent differentiation process.

The difficulty with the above arrangement is, first, the olivine-basalt, which we are obliged to couple with the rhyolite under No. 3. The existence and relations of this basalt in the Sierra Nevada seems to be well established. The second difficulty arises from the fact that the rhyolite No. 3 is of exactly the same acid type as the rhyolites under 1 and 5. From this fact the idea originates that rhyolite No. 3 may be also a recurrent lava, and that we have in the whole volcanic succession portions of three instead of two cycles of differentiation.

On testing this hypothesis we are struck with the fact that andesites 2 and 4 have identical phases, although the groups as a whole differ as stated in the above list. At Eureka the earlier and later andesites were held to be separate, the earlier ones

being more siliceous and not approaching the later ones more nearly than by 2.25 per cent. of silica.[1] At Washoe, however, the pyroxenic andesites, which precede the more siliceous andesites representing at Eureka the earlier group, become equally basic with the andesites of the second period. In other portions of the Great Basin also the andesites belonging to the first and second periods are often indistinguishable.

On studying the general succession, as partially set forth in the table of correlations, we find that the break between Nos. 3 and 4 in the succession is as abrupt as that between Nos. 1 and 2. On the other hand, between 2 and 3 there are many transitional phases, and also between 4 and 5.

We may represent the facts above noted, graphically, as follows:

1. Rhyolite.
2. Andesite.
3. Rhyolite (and basalt).
4. Andesite.
5. Basalt (and rhyolite).

The break between 3 and 4 was noted by Mr. Hague at Eureka.[2] He ascribed it to a change of magmas and argued that the first members of the succession at Eureka, beginning with hornblende andesite and ending with acid rhyolite, were derived from a magma distinct from that which produced the later members of the succession, beginning with pyroxene andesite and ending with basalt. In the first group Mr. Hague found, between the andesite and the rhyolite, gradual transitions which grew continually more siliceous; likewise in the second group he found gradual transitions between the pyroxene andesite and the basalt. This implies two distinct processes of differentiation, the first of which proceeded from intermediate to acid, while the second followed the opposite order, from intermediate to basic. Mr. Hague's interpretation of the development of lavas at Eureka may be graphically represented as follows:

[1] Monograph XX, U. S. Geol. Surv., p. 269.

[2] Monograph XX, U. S. Geol. Surv., pp. 254, 269, 270, 271.

Feldspathic Magma: HORNBLENDE ANDESITE. → ACID RHYOLITE. Series growing gradually more siliceous.

Pryoxenic Magma: PYROXENE ANDESITE. → BASALT. Series growing gradually more basic.

The *general* succession in the Great Basin region, as set forth in the table which we have made opposite this page, corresponds to Mr. Hague's conception (leaving out of the question the rhyolite No. 1, which is not exposed in the Eureka district). The relations of the lavas of the whole region, therefore, omitting the minor exceptions, might be represented as follows:

1. RHYOLITE.

   Break.

2. ANDESITE.

   Gradual transitions.

3. RHYOLITE.

   Break.

4. ANDESITE.

   Gradual transitions.

5. BASALT.

Nevertheless, the exceptions are frequent enough to demand recognition. Observations at several points outside of the Eureka district prove that basalt No. 5 has a closely associated rhyolite which is plainly complementary. Similarly, rhyolite No. 3 has in the Sierras an associated olivine-basalt, which is also probably complementary. Upon looking carefully, we find that there are complementary phases for the stages intermediate between the andesite No. 4 and the basalt No 5; and we become

PROVISIONAL CORRELATION OF TERTIARY LAVAS IN GREAT BRITAIN

Eureka Hague	Washoe Hague	Sierra Nevada (Turner)	Sierra Nevada (Ransome)	Tintic Range, Utah (Tower and Smith)	Lake Mono (Russell)	Pine Nut Range	Sweetwater Range	Gabb's Valley	Ralston Desert	Schell Creek Range	Egan Range	Meadow Valley Canyon	Panamint Range	Randsburg Region
						Biotite rhyolite (granite and alaskite)	Rhyolite (granite)		Rhyolite Tordrillite			Biotite rhyolite	Rhyolite	Biotite rhyolite
Hornblende andesite Hornblende mica andesite Dacite	Pyroxene-hornblende andesite (diorite and diabase) Hornblende-mica andesite (mica diorite, diorite porphyry) Dacite				Hornblende andesite	Hornblende-pyroxene biotite andesite Hornblende biotite andesite	Hornblende-pyroxene andesite	Biotite andesite			Dacite-andesite		Andesite	
Rhyolite	Rhyolite	Rhyolite Basalt	Biotite rhyolite Olivine-basalt	Biotite rhyolite		Rhyolite		Biotite rhyolite	Rhyolite	Biotite rhyolite				
Pyroxene andesite	Pyroxene andesite	Hornblende pyroxene andesite, tuffs, and breccias Pyroxene andesite	Hornblende-pyroxene andesite breccia Latites { Augite-biotite hornblende latite Biotite-augite latite } Hornblende pyroxene andesite breccia	Pyroxene-hornblende-biotite andesite, tuffs, and breccias Pyroxene-hornblende andesite (latite and monzonite)		Hornblende pyroxene andesite, tuffs, and breccias	Hornblende-pyroxene andesite, tuffs, and breccias Hornblende biotite latite (breccia)	Hypersthene hornblende aleutite		Pyroxene aleutite		Pyroxene andesite breccia and tuff, Biotite-hornblende quartz-latite Biotite hornblende dacite Biotite-hornblende rhyolite		Hornblende pyroxene-biotite aleutite
Basalt	[illegible] (diabase)	Basalt	Olivine basalt	Olivine-basalt	Basalt Hypersthene andesite, verging on basalt Rhyolite	Rhyolite Basalt (hornblende basalt)	Basalt	Augite basalt	Olivine-basalt		Basalt	Rhyolite Pyroxene olivine-basalt Rhyolite tordrillite	Pyroxene aleutite and basalt (often olivine-bearing)	Pyroxene basalt Pyroxene olivine-diabase porphyry (dike)

aware that these complementary forms constitute an acid-growing series, transitional between the andesite No. 4 and the rhyolite which is complementary with No. 5, and that this series appears to be in general contemporaneous with the basic-growing series between the andesite and the basalt. As an example of this acid-growing series consecutively observed, the section described in Meadow Valley Canyon is highly interesting; here we have a transition from pyroxene andesite through intermediate phases to Pleistocene rhyolite, which is complementary with Pleistocene basalt.

Between the andesite No. 2 and the olivine-basalt which is coupled with the rhyolite No. 3, we have not found such satisfactory transition phases, but this is perhaps due to the remoter age of this group of lavas.

We may, therefore, write the general succession and relation of the lavas of the Great Basin, as follows:

1. BIOTITE RHYOLITE AND TORDRILLITE.

2. PYROXENE-HORNBLENDE ANDESITE.
   - Hornblende-pyroxene andesite.
   - Hornblende andesite.
   - Biotite andesite.
   - Hornblende quartz-andesite.
   - Dacite.
   - Latite (?)[1]

   Pyroxene andesite (?)

3. BIOTITE RHYOLITE. OLIVINE-BASALT.

[1] Compare some of the analyses of the earlier andesites and dacites at Eureka (e. g., Mon. XX, U. S. Geol. Surv., p. 264, Nos. 4, 5, and 6), with those of latites given by DR. RANSOME (Bull. 89, U. S. Geol. Surv., p. 66).

PYROXENE-HORNBLENDE ANDESITE.

	Pyroxene andesite.	Hornblende-pyroxene andesite.
4.	Hornblende-pyroxene-biotite aleutite.	Augite-biotite-hornblende latite.
	Hypersthene-hornblende aleutite.	Biotite-augite-hornblende quartz-latite.
	Pyroxene aleutite.	Biotite-hornblende dacite.
	Pyroxene olivine-aleutite.	Hornblende-biotite latite.
5.	Hornblende basalt.	Biotite-hornblende rhyolite.
	Augite basalt.	Biotite rhyolite.
	OLIVINE-BASALT.	ULTRA ACID RHYOLITE OR TORDRILLITE

It therefore appears that we have the representatives of two complete cycles of differentiation, and probably the end of a still earlier cycle. During the first completely recorded cycle (beginning with the earlier andesites) the more siliceous rocks were continually extravasated in preference to the more basic complements, so that the acid-growing series is far more prominent in the record than the basic-growing one. On the contrary, during the second or last complete cycle the more basic rocks were continually thrown out in preference to the more siliceous ones, making the basic-growing series more prominent. The laws which govern these apparently eccentric preferences of eruption are yet unknown.

I have looked in vain in the field for the earlier representatives of the first cycle of differentiation, to which No. 1 belongs. If they were erupted previous to the appearance of the rhyolite (No. 1) they have not yet been determined.[1]

[1] What may possibly be one of the members of the earlier differentiation cycle, older than the rhyolite, occurs in the Walker River Range. Here the granite and alaskite, which are considered by the writer as probably the deeper-seated equivalents of the basal rhyolite of the Great Basin section, are evidently younger than and at times intrusive into a great body of biotite-hornblende quartz-monzonite. A similar hornblende-biotite quartz-monzonite was found east of the Walker River Range, in Gabb's

Reasoning on the basis of the deductions specified, we may speculate briefly concerning the cause of the two revolutions, the reappearance of the intermediate magma, and the exhaustion of the old, highly differentiated magmas. In explanation of this, the hypothesis may be advanced that magma basins or lava reservoirs may be almost entirely exhausted by the expulsion of lavas to the surface, and that this emptying may permit refilling by new material from lower regions.[1] It is very possible that the processes of differentiation can only go on under certain circumstances, such as are probably afforded by the comparatively quiet magma basins, and that in the lower regions there may be so much mixing that segregation is impossible.[2] Therefore, when the magma basin is exhausted and receives a new supply from below, it is of material similar to that which filled the basin before differentiation altered it. It is probable that in this way the history of many petrographic provinces, when closely studied far back into geologic time, will be found to be not a simple, single process, but a succession of several or many differentiation cycles, some of which will probably be found to be complete, and some interrupted by this or that accident. It is probable that the existence of recurrent lavas will be found true at many points.[3] In Alaska the writer has found that the

Valley, and here was considered to be extrusive. The writer's grounds for considering that the Walker River Range granite is equivalent to the basal rhyolite cannot be given in this paper, but will appear subsequently. If they prove sound, then the older monzonite very likely represents a pre-rhyolitic monzonitic effusive rock, or at least a less siliceous pre-rhyolite magma.

[1] Since writing the above the writer has chanced upon the following sentence of IDDINGS ("Origin of Igneous Rocks:" Bull. Phil. Soc., Washington, Vol. XII, 1892–4, p. 179): "It is also possible to find a recurrence of different varieties at one center of eruption, which may be accounted for by supposing successive supplies of magma from some depth, which differentiate into similar varieties before their final eruption," He also finds that the same idea had been previously expressed by Sir Archibald Geikie (Quar. Jour. Geol. Soc., London, Vol. XLVIII, 1892, p. 178), as follows: "And as the successive protrusions took place within the same circumscribed region, it is evident that in some way or other, during the long interval between the two periods, the internal magma was renewed as regards its constitution, so that when eruptions again occurred they once more began with basic and ended with acid materials."

[2] IDDINGS (op. cit., p. 196) considers that the general or undifferentiated magma remains undifferentiated on account of being solid, that is, being in a state of potential liquidity.

[3] GEIKIE (op. cit.) in his study of the history of volcanic activity in Great Britain

probably Silurian basalt or basaltic diabase of the Rampart series is identical in composition with the olivine-basalts of the Pliocene.[1] Yet between these two periods a great variety of volcanic rocks, including other basalts, appeared in Alaska.

In studying the succession of lavas it must be borne in mind that the processes of differentiation are quite independent of the causes which produce the expulsion of lavas. Therefore, while the differentiation in a magma basin may go on so that all intermediate types between the initial intermediate one and the final extremes are represented, yet the causes producing eruption will probably occur only at different points in this process, so that the record will be only partial and perhaps not to be interpreted except by comparison with other localities. For this reason, the observed succession must be studied with regard to its general aspects rather than to its details. In interpreting the succession, also, the possibility, or even probability, of many intermediate forms being brought about by accidental mixing during the general processes of differentiation, must be borne in mind. This error may be eliminated if at each period of vulcanism we select the extreme important types, omitting the associated intermediate ones as possibly formed by mingling. The variations introduced by mingling and those brought about by irregular volcanic eruptions are such that it is difficult to apply to them any law. It has been assumed, for example, that in general basalts overlie rhyolites where these occur close together. This is held by Messrs. Hague and Iddings[2] as well as by previous observers. But Marvine[3] observed, in the Colorado River region, basalt lying upon rhyolite, and the present writer observed the same relation in the Pleistocene lavas of Meadow Valley canyon, which is a part of the drainage of the Colorado.

J. E. SPURR.

from the earliest pre-Cambrian times to the Tertiary, has found that similar rocks recur at many different points in the succession. He finds also similar series, so that he is led to divide the whole succession into natural groups or periods of volcanic activity. See also IDDINGS, op. cit., pp. 145, 179, 196.

[1] Geology of the Yukon Gold District. Eighteenth Ann. Rept., U. S. Geol. Surv., Part III, Economic Geology, p. 241.

[2] Mon. U. S. Geol. Surv., Vol. XX, p. 86.

[3] U. S. Geol. Surv., W. 100th Mer., Part III, p. 205.

THE GLACIER OF MT. ARAPAHOE, COLORADO

On the fourth day of August 1900, I was one of a party of seven men who ascended Mt. Arapahoe. This mountain is the highest of a small group of peaks on the Continental divide in Colorado. It is situated about latitude 40° 1′ N. and longitude 105° 38′ W.[1] and has an elevation of 13,520 feet above sea level. There are several peaks of nearly equal altitude in the group, but they are so intimately connected that they form practically one mountain. The group is locally known as "The Arapahoes." The peaks, together with their spurs and connecting ridges, nearly encircle a large enclosure in which the north branch of Boulder Creek rises. In the southern part of this enclosure is a well-defined cirque which is partitioned off by a spur extending into the enclosure from the side of the highest peak. This spur forms the north wall of the cirque. Its west and south walls are formed by Arapahoe Peak proper and the peak next south, together with their connecting ridge, which is but little lower than the summit of the peaks. The east wall is formed by a third peak, the summit of which is a few hundred feet lower than the other two and joined to the peak on the south side by a moderately high ridge. The cirque opens toward the north-east by a constricted passage into Boulder Creek valley.

The inner slopes of the cirque are precipitous on all sides. In only a few places can they be climbed in safety. The accompanying photograph, Fig. 1, taken from a high point and looking downward, does not adequately represent the degree of slope. The south wall is, in places, nearly vertical. The naked cliffs rise something like 1000 feet in the clear. But at the southwest and west sides the slopes are such that great masses of snow and ice of unknown depth lie upon them, reaching from the main mass at the bottom of the cirque, to the top of the ridge. The largest of these arms is shown in

[1] Hayden's atlas of Colorado.

FIG. 1.—View of the Arapahoe glacier from below.

the illustration Fig. 1. The peak with its perpendicular cliffs forming the south wall, together with about one third of the cirque, is cut off from view by the bluff in the foreground. Figure 2 is a near view of this peak showing the upper extremity of one of these arms of snow and ice.

The cirque presents exceptional advantages for the accumulation and preservation of snow and ice:

1. The encircling peaks and ridges are barriers behind which the drifting snow accumulates during the winter. From whatever direction the wind blows, except from the northeast, its velocity is checked by the peaks and ridges forming the walls of the cirque, and the cirque receives its burden of snow. The importance of this mode of accumulation is well illustrated in the long snow drifts which are common along the high ridges throughout the mountains where the winds have dropped their burden in the lee of the crests. In some instances the summer's heat is not sufficient to melt away these drifts even where they lie exposed to the sun on the south side of the ridges.

2. The snow and ice of the cirque are more or less protected from the heat of the sun, by the elevated rim which is highest, and the inner slope steepest, on the south and west sides. On these two sides where the slope is gentle enough to permit it, lie accumulations of snow and ice of unknown thickness, extending from bottom to top of the walls. On the northern side, *i. e.*, the southern slope of the spur, the snow and ice reach but a little way up the side. This may be due in some measure to a difference in the amount of accumulation of snow, but it is certainly due primarily to the greater melting power of the sun on the slope facing southward.

3. The snow and ice of the cirque are also protected by sheltering from the east, south, and west winds. While our party was on one of the peaks overlooking the cirque, a thunder storm from the southwest enveloped the mountain. After the wind had swept the clouds from the southwestern side of the mountain, the cirque remained full of thick mist. The wind which was blowing at a moderately high rate of speed, cut off

FIG. 2.—The south peak of the Arapahoes, showing the upper extremity of one of the smaller arms of the glacier.

the cloud mass even with the crests of the ridges, and passed completely over the cirque instead of descending into it in any notable measure, and sweeping the mist away. For nearly half an hour after the clouds had been swept away from the windward slope of the mountains, the cirque was more or less obscured by shifting and eddying mists. These were at first parts of the original cloud. Later they were mists formed within the cirque. The latter formed the better index to the action of the winds. From their behavior it was evident that only secondary air currents came in actual contact with the snow and ice of the cirque.

Within the cirque the snow and ice are nearly all collected into two masses. These seem to be essentially independent of each other, and are separated by a ridge of débris. To the east of this ridge is the smaller of the two. To the west of the ridge is the larger—the main mass of snow and ice of the cirque. The larger field was estimated to be nearly two miles wide. Its length seemed to be approximately the same but I was not in a position to make a satisfactory estimate of the length. Its surface is steeply inclined. In several places where the snow and ice extends to the top of the south wall, we measured the inclination of its surface from above as carefully as possible by holding one climbing staff vertically and sighting down the slope with another. The angle thus given showed an inclination of about fifty degrees. At these points the upper edge which had been melted back at its contact with the cliffs, showed a thickness of twenty to forty feet. Over the bottom of the cirque the slope of the surface of the ice is gentle enough for small bowlders from the cliffs above to lodge on it. This gentler slope was somewhat thickly covered in places with stones and small bowlders. No large bowlders were seen on the surface, but below the lower edge of the ice, are great numbers of rock-masses, ten to twenty feet in diameter or even larger. It is probable that the large bowlders gain momentum enough on the steep slopes above to carry them over the gentler slopes and beyond the edge of the ice

The ice is hard and compact to the surface. Bowlders weighing two hundred or three hundred pounds were rolled down the slopes but made little impression on the surface of the ice. A small lake fifteen feet across and four feet deep was found on the surface. Late in the afternoon I found that the ice had softened scarcely enough during the day to prevent me from slipping even on comparatively gentle slopes.

The mountaineers who are familiar with the Arapahoes, had warned us against descending over the ice on account of crevasses. An opening seen about five hundred feet below the top of the ridge and which appears as a broken line in the illustration (Fig. 1) is presumably a crevasse. Others were seen from a distance which were not so well defined. I had no opportunity for close inspection. The mountaineers gave me somewhat careful descriptions of the openings, and told of a man who had been lost presumably in a crevasse. Their search for him resulted in finding nothing but his overcoat. From the descriptions given by these men, and from what I saw of the snow and ice, I am convinced that true crevasses are to be found there.

The stratified nature of the ice is seen along the steep face of its lower edge. Dark bands, probably due to the accumulation of foreign material on the surface during the summer, alternate with lighter bands. Some of the individual bands were traced, with the aid of the field glass, for long distances. Only the uppermost of these bands can be distinguished in the accompanying photograph. This is seen as a light line along the upper edge of the face of the ice, and is due to the whiteness of last winter's snow. On the surface of the ice at the right and a little way back from the edge, is a dark spot where the fresh white snow has been removed from the darkened surface of an older accumulation.

Along the base of the eastern rim of the cirque, a relatively small amount of snow and ice accumulates to form the smaller field. Its tendency to movement indicated by the slope of its surface, is diagonally opposed to that of the greater mass moving from the west and south. Over the surface of this smaller

mass I descended for about a mile but discovered no unquestioned evidences of movement of the ice. Between this and the edge of the greater mass to the west, a large ridge of débris has been formed. The ridge is inconspicuous at its inception near the upper end of the smaller ice field, but farther down it increases in size until near the outlet of the cirque it assumes notable proportions. In former times the upper part of this ridge now separating the two snow fields, was probably a medial moraine. But the recession of the ice has changed it into a terminal moraine throughout the greater part of its length. The ridge is crescent shaped and conforms rather closely to the edge of the ice. It has two more or less distinct crests—an outer large one, and an inner small one. Between the smaller crest and the edge of the ice, is a well defined trough.

There is a shallow lake a short distance below the edge of the ice. From an eminence on which I stood looking down upon this lake, I noticed that the current, produced by the stream flowing into it from the ice above, could be plainly traced for several rods by its whiteness which was presumably due to the rock flour derived from the ice above. This was not present in sufficient quantity to attract my attention in the running stream. But the contrast in color as the whitened water of the stream entered the green water of the lake was conspicuous. Closer inspection strengthened the conclusion that the stream carried rock flour.

The size of the ice mass; its great though unknown depth; the steep inclination of its surface; its stratification and crevasses; its terminal moraine; and the rock flour of its stream, all point to the inference that this field of snow and ice constitutes a true glacier.

The valley into which the cirque opens is one of broad bottom and precipitous sides. The side walls are nearly vertical in many places. Its floor is occupied by a chain of lakes interrupted in several places by groups of poorly formed roches moutonnées. Most of the lakes are in rock-hewn basins, but some are formed back of débris dams. One in particular, near

the head of the valley, is a beautiful example of the latter. It rests behind a crescent shaped ridge—a comparatively recent terminal moraine. Fragments of terminal moraines extending partly across the valley bottom, occur in several places near the head of the valley.

Résumé.— 1. The exceptional amount of snow and ice in the cirque at Mt. Arapahoe is due to the unusual advantages presented for its accumulation and preservation. These consist (*a*) in trapping the drifting snow, and (*b*) in protecting it from sun and warm winds. 2. Within the cirque are two fields of snow and ice which are essentially independent of each other at the present time. The larger field is estimated to be something like two miles in width and about the same in length. 3. The snow and ice of the larger field constitutes a glacier. This is attested (*a*) by the amount of snow and ice there accumulated, and by the inclination of its surface which varies from about 10° to 50°; (*b*) by its stratification indicated by the banding of the face; and (*c*) by its movement, indicated by the crevasses, the moraines, and the rock flour. 4. This glacier is the survivor of a much larger glacier which formally occupied the upper part of Boulder Creek valley.

WILLIS T. LEE.

THE SHENANDOAH LIMESTONE AND MARTINSBURG SHALE[1]

INTRODUCTION

WHILE engaged in fieldwork on the Maryland Geological Survey, the writer has had an opportunity to examine to some extent the upper part of the Shenandoah limestone and the overlying Martinsburg shales.

Shenandoah limestone.—The name Shenandoah was proposed by Mr. Darton in 1892 for the limestones of the Shenandoah Valley and the formation was described in the vicinity of Staunton, Va., as consisting of "a great mass of impure magnesian limestones below, grading upwards through a series of cherty beds of no great thickness into several hundred feet of light-colored, heavily bedded purer limestones. The lower beds were not found to be fossiliferous. In the cherty beds only a few middle Ordovician gasteropods were found. . . . . The upper member is sparingly fossiliferous at many localities with a middle to upper Ordovician fauna in which the forms *Orthis occidentalis*, *O. testudinaria*, *Leptæna alternata*, and *Chætetes lycoperdon* were predominant. *Pleurotomaria subconica*, *Conularia trentonensis*, *Platynotus trentonensis*, and several others were also noted."[2]

Mr. Darton in his account of this formation in the Staunton folio described an upper member of the limestone from 200 to 350 feet in thickness which is said to be purer, more thickly bedded and generally of lighter color than the older part of the formation. It is also stated that in the upper division "fossils occur also in greater or less profusion throughout its course. The fauna is that of the Trenton limestones of New York."[3]

Martinsburg is near the northwestern corner of the Harper's Ferry sheet which was mapped by Mr. Arthur Keith,[4] and the

[1] Published by permission of Dr. Wm. Bullock Clark, State Geologist of Maryland.

[2] Amer. Geol., Vol. X, p. 13. [3] Geologic Atlas of the U. S., Folio 14, 1894, p. 2.

[4] Geologic Atlas of the U. S., Folio 10, 1894.

line between the Shenandoah limestone and the Martinsburg shale is clearly shown in the vicinity of that city, but the description of the formation gives no additional information regarding its age.

Professor Wm. B. Rogers considered that the Trenton, Utica and Hudson River formations were represented in the Potomac Valley at Williamsport and to the west; but he apparently regarded the greater part of the limestone as of Chazy, Levis and Calciferous age.[1]

Martinsburg Shale.—The name Martinsburg shale, like that of the Shenandoah limestone, was proposed by Mr. Darton from the exposures near Martinsburg, W. Va., "a region in which," he states, "the formation is extensively and typically exposed." It is stated that at the base there is "a thin series of alternating thin bedded limestones and slates" but for the most part the rocks of the formation "are slates and shales, mainly of dark color. . . . . The beds are fossiliferous at many points; graptolites are found in the basel beds, notably in some light colored weathered shales in cuts of the Chesapeake and Ohio Railway, two miles east of Staunton and further east; along the Little North Mountain, and in the Warm Spring, Crab Bottom and other anticlinal valleys westward, remains of upper Ordovician brachiopoda are moderately abundant. The forms most frequently met with are *Leptæna sericea*, *L. alternata*, *Orthis testudinaria*, *O. pectinella*, and *Modiolopsis modiolaria*. The precise equivalency of the formation is not known, but judging from its general relations and fauna it probably comprises the Utica, Hudson River and possibly small amounts of adjacent formations of the New York series. It is the No. III of Rogers' reports and has generally been called 'Hudson River.'"[2]

Under the description of the formation in the Staunton Folio Mr. Darton states that "In the Jack Mountain exposures fossils are abundant, and the species are of Hudson age," while "In the

[1] See Plate No. VII, Sec. No. 1, in "A Reprint of Annual Reports and other papers of the Geology of the Virginias," edited by Jed. Hotchkiss, 1884.

[2] Amer. Geol., Vol. X, pp. 13, 14.

beds east of Churchville and in the buff and red slates at the base of the formation in cuts two miles east of Staunton, Utica graptolites occur in considerable abundance."[1]

Mr. Keith, apparently, did not have a very clear conception of the lithological character of this formation for he states in his description that "It consists of black and gray calcareous and

FIG. 1.—Parson's quarry in Shenandoah limestone, near Martinsburg, W. Va.

argillaceous shales of fine grain, and shows no variations within this area."[2] It will be seen in the following description that after the thin argillaceous shales in the lower part of the formation there are shales alternating with greenish micaceous sandstones. Again there is confusion in reference to the period to which the formation belongs for in the description it appears under the Cambrian,[3] and under the "columnar section"[4] and legend of the map as Silurian.

[1] Geologic Atlas of the U. S., Folio 14, p. 2.

[2] Geologic Atlas of the U. S., Folio 10, p. 3. [3] *Ibid.*, p. 3. [4] *Ibid.*, p. 5.

DESCRIPTION OF SECTIONS

What follows in this paper in reference to the Shenandoah limestone relates more particularly to the upper part of that formation which was studied to some extent in the vicinity of Martinsburg, West Virginia, and Pinesburg, Maryland.

Limestone and shale near Martinsburg.—1. Along the Baltimore and Ohio Railroad immediately east of Martinsburg station are exposures of the upper part of the Shenandoah limestone. At the western end of the cut, just east of the railroad bridge over Tuscarora Creek, are dark blue, fairly massive limestones, some of which, however, on weathering split into quite thin, irregular layers (Fig. 1). These limestones are fossiliferous, two species of *Lingula*, together with some other forms having been noticed, and the rocks closely resemble many parts of the typical Trenton limestone of New York. In the eastern part of this cut, near the switchtender's station, there are thin layers of dark blue limestone which alternate with dark blue to black calcareous shales containing fragments of graptolites, and this part of the cut shows a transition from the massive limestones of the Upper Shenandoah to the lower shales of the Martinsburg formation. This part of the section is shown in Fig. 2.

3. To the east of the switch cut the rocks are covered for some distance; but about one half mile east of the station is Cemetery cut, where several hundred feet of quite thin, even, bluish, somewhat argillaceous shales are well shown. These may be seen in Fig. 3. In a rather hasty examination no fossils were found and the lithological character of these shales is rather more like that of the Hudson in New York than the Utica shale.

4. To the east of Cemetery cut is a covered space and then another railroad cut in shale follows. These shales which are mainly blue and arenaceous closely resemble lithologically the Hudson shales of the Mohawk Valley and Eastern New York, and alternating with them are thin layers of greenish, micaceous sandstone similar to those in the lower part of the Hudson in

numerous localities in New York. In the western part of the cut are some rather thin, blackish, argillaceous shales.

In the southern part of Martinsburg, operated by the Maryland Limestone Quarry Company, are extensive quarries in the massive Shenandoah limestone, large quantities of which are

FIG. 2.—Transition from Shenandoah limestone to Martinsburg shale in switch cut on B. & O. R. R. east of Martinsburg, W. Va. The men are standing opposite the upper part of the Shenandoah limestone and the Martinsburg shale is to the right.

shipped to the steel and other furnaces in the vicinity of Pittsburg. The limestone is mainly a light colored drab and this part is reported as the purest and best for flux. No fossils were found in the limited time given to the search and one of the quarrymen said he had never noticed any.

Exposures near Pinesburg, Md.—A number of the exposures in the vicinity of Pinesburg station on the Western Maryland

Railroad in the southern part of Maryland, about thirteen miles north of Martinsburg, proved more fossiliferous than those in the vicinity of Martinsburg.

1. The Pinesburg quarry is on the Western Maryland Railroad, a short distance west of the station. There is an exposure of about fifty feet, the southern and higher part of the quarry furnishing dimension stone which is dark blue to almost black in color with banded layers of blue and bluish-gray and contains fragments of trilobites, crinoid stems and some other fossils, while the northern and lower part is used mainly for ballast. The dip is 20° E. A view of this quarry is given in Fig. 4.

2. A short distance to the east of the quarry is an excavation in massive drab limestone, some of which before weathering is dark in color, but afterward it is all a light gray. Fossils are rare. Several specimens of *Leperditia*, a *Rhynchonella*, a fragment of a *Leptæna* similar to *alternata* and fragments of some other fossils were found.

3. On the railroad, between the quarry and the station, is a small cut through thin bedded, dark blue, compact limestones and some shaly layers. Fossils are common in some of these layers and on one a large number of poorly preserved and crushed specimens of *Asaphus platycephalus* Stokes were found. The complete list of species found in this cut is as follows:

1. *Asaphus platycephalus* Stokes.
2. *Monticulipora* (*Prasopora*) *lycoperdon* (Say).
3. *Calymene callicephala* Green (?).
4. *Lingula rectilateralis* Emm. (?).
5. *Plectambonites sericea* (Sowb.).
6. *Orthis* (*Dalmanella*) *testudinaria* Dal.
7. *Rhynchotrema inæquivalve* (Castelnau) (?).

The rock has been quite badly crushed, but in lithological appearance it closely resembles the Trenton limestone in New York. This limestone ledge is near the top of the Shenandoah formation, for the Martinsburg shales occur only a short distance to the east by the side of the road at the Pinesburg station

and to the east of "Slate Ridge." The weathered shale is a gray to an olive-grayish color and is very argillaceous. It is to be noted that the lower shales of the Martinsburg are argillaceous and calcareous, while the arenaceous ones finally alternating with

FIG. 3.—Martinsburg (Utica) shale in Cemetery cut, on B. & O. R. R., one half mile east of Martinsburg, W. Va.

sandstones, occur higher in the formation. This part of the formation, composed mainly of thin bedded, micaceous, somewhat buff-colored sandstones, alternating with some olive argillaceous and arenaceous shales, may be seen by the side of the highway west of Williamsport, Md., and in the western part of the town.

CONCLUSIONS

The fauna found in the railroad cut at Pinesburg is composed of species which are of common occurrence in the Trenton limestone of New York, and the lithological appearance of the rock is that of typical thin-bedded exposures of that limestone. There seems no question but that the upper part of the Shenandoah

FIG. 4.—Shenandoah limestone in the Pinesburg quarry west of Pinesburg, Md.

limestone is correctly correlated with the Trenton limestone. The lower part of the Shenandoah limestone contains Cambrian fossils; but the line of division between the Cambrian and Lower Silurian, which apparently is not indicated by any physical break, has not yet been determined in the Great Valley. It is hoped that future work in Maryland or West Virginia may give us more definite information concerning the composition and limits of this great limestone formation. The bluish to black calcareous and very argillaceous shales which succeed the Shenandoah limestone and form the lower part of the Martinsburg

shales closely resemble the Utica shale, and represent that formation.

In that lithological change from the argillo-calcareous shale, the arenaceous deposits of the succeeding portion of the Martinsburg formation agree with the transition from the Utica to the Hudson shales of New York. This arenaceous part of the Martinsburg shale the writer would correlate with the Hudson shales of New York as exposed in the lower Mohawk Valley and the Helderberg region. In the revised list proposed by Clarke and Schuchert for the New York series,[1] Lorraine beds is probably the name of the formation with which these shales should be correlated. It is to be noted, however, that the deposits which have been called the Hudson formation in the Mohawk and Helderberg region do not contain many of the species, or resemble closely in lithological appearance the rocks in the vicinity of Lorraine, New York.

Charles S. Prosser.

Columbus, O.

[1] Science, N. S., Vol. X, 1899, p. 876.

Reviews

Geology of the Little Belt Mountains, Montana, with notes on the Mineral Deposits of the Neihart, Barker, Yogo, and other Districts, by WALTER HARVEY WEED, accompanied by a report on *The Petrography of the Igneous Rocks of the District*, by L. V. PIRSSON. Twentieth Annual Report of the U. S. Geological Survey, Washington, 1900. Pp. 257–581, with 42 plates and 43 figures.

This voluminous report is based upon field work done in September 1893, and August 1894. The major part of the report was written by Mr. Weed, who describes the position, topography, and geological structure of the region. The rock formations are described in succession from the gneisses, schists, and Algonkian series, through Cambrian and Siluro-Devonian to Carboniferous. The geology of the region is treated in detail, commencing with the southern part of the range, and followed by Judith area, the Yogo, Big Baldy Mountain, Wolf Butte, Taylor Peak, Barker, and Monarch districts, and finally the Neihart.

A chapter is devoted to the general geology, and deals first with the history of the region as interpreted from sedimentary rocks, showing that the same general conditions prevailed in this region as in the rest of the eastern part of the Rocky Mountain area of the state. The uplift of the Little Belt Mountain range is supposed to have been due to lateral compression, but the minor doming and faulting observed at all the larger mountain masses are due to igneous intrusions.

With the exception of Yogo Peak all the prominent mountain masses are formed of igneous rock, whose structural features show that they constitute a group of closely related forms, grading from typical laccoliths to those of plutonic plugs or bysmaliths. The largest of these bodies is exposed over an area of three by five miles, and is probably 3000 feet thick. With these are associated numerous intrusive sheets, but few dikes. There are besides several intrusive rocks not directly connected with the laccolithic bodies. The character and origin of these intrusions are discussed.

The concluding chapter of Mr. Weed's report contains notes on the ore deposits, under the heading: "The Ores, Veins, and Mines." The ores are chiefly those of silver, silver-lead, and gold. Sapphire mines occur in Fergus county, and are said to be the most valuable gem mines in the country. Deposits of limonite and hematite are found in a number of localities and will some day be developed economically.

The petrography of the igneous rocks by Professor Pirsson is a rather full account of the rocks, their mode of occurrence and field relations, texture, and microscopical characters, together with their chemical composition and the estimated quantitative mineral composition. It also considers the general petrology of the region, and closes with a discussion of magmas by graphic methods, and the absorption of sediments by magmas.

The rocks are subdivided into (*a*) granular non-porphyritic rocks, (*b*) acid feldspathic porphyries, (*c*) lamprophyres, (*d*) effusive rocks. In the first group are found representatives of syenites, monzonites, diorites, shonkinites, and aplites. Among the syenites is analcite-(nephelite) syenite, which, unfortunately, has not been analyzed chemically. Syenite, monzonite, and shonkinite occur together as differentiation products of one rock body at Yogo Peak. In the shonkinite the proportion between the dark and the light constituents is $\frac{65}{35}$—that is, the former preponderate. The second group contain representatives of granite, syenite, and diorite classes, and constitute the laccoliths and many of the intruded sheets. Among these rocks there are many transitional types, the transitions being, in several cases, of much more importance locally than the more commonly-known types. Further, these transitions occur not only in different masses, but often in the same mass. The third group includes minettes, which are rather common in this district, besides nephelite-minette, vogesite, and analcite-basalts. Among the minettes is a variolitic facies, the small varioles being spherulites of feldspar. Nephelite-minette is a new variety of rock belonging to the monchiquite-alnoite series of Rosenbusch. Analcite-basalts occur as dikes in several localities. In one case the rock is estimated to contain 49.5 per cent. of analcite, the remainder being pyroxene, olivine, and magnetite. A rock closely allied to analcite-basalt carries the sapphires mined in this region. The sapphires are considered as having resulted from the absorption of fragments of clay shale included in the magma at the time of its

eruption. The fourth group includes basalt, which occurs only in two localities, as extrusive lava.

In the chapter on general petrology of the region it is pointed out that the average composition of all the igneous rocks observed would be that of a moderately acid syenite approaching an acid monzonite in character. The rocks of the larger laccoliths present a somewhat striking similarity in chemical composition and texture. They are generally phanerocrystalline porphyries. They correspond to Rosenbusch's granite porphyritic dike rocks. In this region they are preeminently laccolithic rocks. Their more acidic character must be taken into consideration in this connection, for in other regions less acid rocks occurring in the form of laccoliths exhibit typical granular, nonporphyritic texture. Here, as in other mountain groups of laccolithic character in the Rocky Mountain region, the depths at which the magmas are intruded appear to have exerted no perceptible influence on their granularity. It is evident that chemical composition is an important factor in the production of rock textures.

Differentiation of igneous magmas and the formation of aplitic veins are discussed and the variation in the mineral composition of the rocks at Yogo Peak is expressed diagrammatically. The application of diagrammatic methods to the discussion of chemical variations among rocks of one district is considered with special reference to Yogo Peak and the surrounding region. A comparatively simple mathematical relationship is made out for the principal rocks of the region, which is the more surprising when the intricate nature of the chemical molecules of several of the rock-making minerals is considered. It is perfectly evident, as an abstract proposition, that the chemical composition of any rock is a mathematical function of the several component minerals, whose chemical molecules are more or less variable functions of a few chemical elements. From which it may be inferred that whatever the process by which differentiation of a magma takes place the resulting solutions or magmas will probably sustain a mathematically intricate functional relation to one another. In the present instance the approximate relations appear to be comparatively simple. It is to be noted, however, that the correspondences between observed and estimated composition presented by Professor Pirsson, as he himself remarks, are merely close approximations. They are, nevertheless, striking. With regard to the absorption of sediments by magmas, the study of the igneous rocks in the Little Belt

Mountains shows that there is no evidence in this region in favor of the theory of considerable absorption.

J. P. I.

Geological Survey of Canada. Annual Report of Mineral Statistics for 1898. By E. D. INGALL, Ottawa, 1890. 196 pp.

This report shows an increase of total production for the year covered of 34.89 per cent., a production per capita of $7.32. This is compared with a total increase for the United States of 10.61 per cent., and a per capita production of $9.38, the source of the latter statistics not being given. Compared with previous years, there is a steady and large increase. From a table of proportionate values it appears that gold produces more than one-third (35.63 per cent.) of the whole, leaving coal (21.27 per cent.) well in the rear, while the next on the list are silver (6.71 per cent.) and copper (5.52 per cent.) In the preceding year coal had stood at the head of the list, the change of places being due to the large output of gold from the Yukon.

The total estimated value of metallic and non-metallic products is $38,661,000. The numerous tables usually give the production for several years previous, and afford the means for comparative studies.

C.

On the Subdivisions of the Carboniferous System in Eastern Canada, with Special Reference to the Union and Riversdale Formations of Nova Scotia, Referred to the Devonian System by Some Canadian Geologists. By H. M. AMI, Trans. N. S. Inst. Sci., Vol. X, Session 1899–1900, 17 pp.

The precise scope of the paper is well indicated in the title. The argument proceeds essentially on paleontological lines, and the physical lines of evidence are essentially set aside. In this case these latter embrace unconformities as well as the character of the rocks. The paleontologic evidence embraces plants, crustaceans, insects, mollusks, and amphibia. These are thought to indicate an Eo-Carboniferous age for the Union and Riversdale formations, which have been referred by some Canadian geologists to the Devonian system. The

author's classification of the Carboniferous of Nova Scotia is summarized in the following table :

Formations		Northern areas	Southern areas	Order
Neo-Carboniferous	Cape John	Cape John Sandstones		XII
	Pictou	Pictou Freestones		XI
	Smelt Brook	Smelt Brook shales		X
	Small's Brook	Spirorbis limestones		IX
	New Glasgow	N. Glasgow conglomerates		VIII
		Coal Measures		VII
		Unconformity		
Meso-Carboniferous	Stellarton	Millstone grit	Millstone grit	VI
	Westville		Unconformity (?)	V
	Hopewell		Hopewell and	IV
	Windsor		Windsor	III
		Unconformity		II
Eo-Carboniferous	Union		Union	I
	Riversdale		Riversdale	

T. C. C.

Transactions of the Australasian Institute of Mining Engineers, Vol. VI. Edited by A. S. Kenyon, Sec., Melbourne, 1900; pp. 247.

The following papers make up the contents :

On Safety Appliances and Precautions Necessary in Mines. By J. R. Godfrey (with 17 figures).

Contacts. By W. H. Ferguson.

Some Notes on Dry Crushing. By N. F. White (with 10 figures).

Contouring on Mining Properties with the Aid of the Tachometer. By H. P. Seale (with 10 figures).

Diamond Mines and Alluvial Deposits, South Africa. By P. R. Day.

The Manufacture of Sulphuric Acid and its Use in Metallurgy. By W. H. Mawdsley (with 10 figures).

Mine Stores. By F. Danvers Power.

The Use of Electricity in Mining. By E. F. J. Holcombe Hewlett (with 1 figure).

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Kürzere Originalmittheilungen und Notizen.

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III. Multiplication of Rays and Bilateral Symmetry in the 20-Rayed Star-Fish *Pycnopodia Helianthoides* (Stimpson). By William E. Ritter and Gulielma R. Crocker. Vol. II, pp. 247–274.

IV. The Tree Willows of Alaska. By Frederick V. Coville. Vol. II, pp. 275–286.

V. Notes on the Hepaticæ collected in Alaska. By Alexander W. Evans. Vol. II, pp. 287–314.

VI. The Bryozoa. By Alice Robertson. Vol. II, pp. 315–340.

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CORRECTIONS

1. In his review of Professor Davis' paper on "Glacial Erosion in France, Switzerland and Norway," in the last number of the JOURNAL, the reviewer said (p. 571): "If there is any reference in the paper to similar discordance between main valleys and tributaries not in any way connected with glacial erosion, it escaped the eye of the reviewer." Such reference occurred in the article, on page 283, lines 8–9, in the following words: "It should be noted that discordance of side and main valleys may also be found where a large river has lately been turned to a new path, as in the normal progress of the capture of the upper course of one river by the headward gnawing of the branch of another river (see reference to Russell below), or in the new arrangements of drainage lines in a region from which a glacial sheet has lately withdrawn." T. C. C.

2. In the article on "Methods of Studying Earthquakes," by Professor Davison, the words, "with a large number of observations—they are as a rule," on p. 305, opposite the middle of Fig. 1, should be transposed to the opposite page and inserted after the second line of the first complete paragraph, so as to read: "But the method of intensities does more than this. When the isoseismal lines are carefully drawn—and this is only possible with a large number of observations—they are as a rule roughly elliptical in form; their longer axes are parallel or nearly so, but they are not coincident."

In the eighth line of the same paragraph, "focus" should read "forms." C.

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PRINCIPLES OF PALEONTOLOGIC CORRELATION.[1]

CONTENTS

General discussion.—Geologic correlation has been carried on ever since the pupils of Werner endeavored to recognize his stratigraphic divisions in remote parts of the earth; and since William Smith discovered that fossils are characteristic of certain formations, paleontologic correlation has been attempted. Still it must not be forgotten that the greater part of the correlation that has been done up to this time is based on lithologic and stratigraphic rather than on faunal data. Fossils have been regarded as incidental, useful in recognizing strata, but not as a basis for subdivisions on account of changes in fauna or flora.

Where a rock-bed of distinctive character is persistent over a wide extent of country, a lithologic correlation would reach as good, and often even better, results than could be obtained from

[1] Read before Section E. Amer. Assoc. Adv. Sci., June 28, 1900.

paleontologic data. But outcrops of strata are deceptive, and often apparently continuous beds of the same character turn out to contain a number of different formations. In the western states such lithologic and stratigraphic correlations have been, more often than not, erroneous, while in the Mississippi valley region they have usually been at least approximately correct, because the great geologic events that were the causes of the stratigraphic changes were uniform over wide areas. Even today the catastrophe doctrine of Cuvier makes itself felt, and we find paleontologists and stratigraphers using unconformities as a basis for the separation of Cretaceous from Jurassic, where the fossils do not tell a definite story, as if the uplift and erosion would necessarily come at the same time in Europe and America.

Paleontologic correlation itself is not infallible; it must be used intelligently, its sources of error known and guarded against, or else it is little more reliable than the lithologic method; these errors lie chiefly in defective knowledge of the vertical and horizontal range of species or genera chosen as criteria, and in erroneous identification of these forms. Careful collecting, accurate field and laboratory discrimination, and wide knowledge of the literature are the best safeguards.

Two sorts of paleontologic correlation may be recognized, the direct, and the indirect method. In a limited province, such as existed in England and France during Cretaceous time, faunas were distributed uniformly over the area and had the same range in the two countries. Thus correlation of English and French Cretaceous strata is simple and direct, for they represent sediments that were once continuous, that were laid down in the same basins or along the same margins, under the same climatic conditions, and contained the remains of a similar fauna.

On a larger scale the problem of correlating the western European Cretaceous beds with those of the Atlantic slope Cretaceous of North America is the same. These strata were all deposited in the same faunal region, and although there are provincial differences the American and the western European faunas are remarkably similar, with even many species in common to

the two provinces, and most of the genera. During Cretaceous time there must have been easy intercommunication between Europe and America by a submerged continental shelf, keeping well within the temperate conditions. This state of things persisted through the Eocene, for the same similarity of faunas has been noted on the two continents in strata of that period.

On a still larger scale the same sort of correlation has been carried out between the western American and the Alpine Upper Trias, where many of the species and nearly all the genera are common to the two localities, although they are not in the same province, nor even in the same faunal region, and separated by six thousand miles in a direct line, and by at least twelve thousand miles by the nearest direction in which migration could have taken place. Yet there must have been easy intercommunication by continental margins from the American region, through the Oriental, to the Mediterranean region, along the borders of the ancient Mesozoic "Tethys" or central Mediterranean sea, that stretched eastward from the Alpine province through Asia Minor, India, and at least to the borders of China and Japan.

Direct correlation is possible even where there is no community of species, if a number of characteristic short-lived genera be common to the two regions. Thus the student of stratigraphic paleontology has no difficulty in correlating the *Meekoceras* beds of the Lower Trias, whether they occur in the Himalayas, Siberia, California, or Idaho; the fauna is essentially similar in all these regions, although species common to them are not yet identified. These faunas must have had a common origin either in one of these regions or in some unknown outside region, and reached the American and Asiatic provinces by migration. The place of origin may have been distant enough for the migrant faunas to have become specifically differentiated by the time they had reached their distant goals. In fact this is probably by far the more common case. Absolute specific identity between regions as distant as Asia and America must be rare; in reality there are usually in common to such regions only what

are called "representative species." This is especially true in a time of quiet development, where the fauna is largely endemic, and where there was no chance for outside elements to get into the region.

Indirect correlation also may be of two kinds; the first of these is where no fossils of extra-regional distribution are known in a formation, but where the formations above and below can be recognized. An example of this is the classification of the Algonkian system or its equivalents; the clastic pre-Cambrian, and post-Archean sediments all over the world are placed in this division, although no fauna that is characteristic is known in them as yet. Such correlation can only be tentative or preliminary, as is the present classification of the Newark formation of the Atlantic coast.

The second sort of indirect correlation is where no fossils are common to two separated regions, but elements of both are found together in a third region. A good example of this is the correlation of the Cretaceous strata of the west coast of North America with those of the interior and the Atlantic region. During the greater part of Cretaceous time the two regions were separated by a land mass so that their faunas were totally distinct, not only the species but even the genera being different. And these difficulties are seen in the attempts of the earlier stratigraphers to assign the various formations to their proper places. But when the Indian Cretaceous fauna was described, it was seen at once that there were striking analogies between that and genera and species of California. And since the Indian formation was accurately correlated with the Cretaceous of Europe, it became comparatively easy to assign the Californian strata to their proper place by this indirect comparison with the European standard. The Cretaceous of the Atlantic region had long before this been correlated with European, and thus the formations of the Atlantic region and of the Pacific coast were finally placed in harmony through the medium of comparison with a region thousands of miles from either.

Paleontologic zones.—Ever since William Smith demonstrated

that the various beds of the English Jurassic may be recognized by their fossils, the stratigraphy and paleontology of this formation have been a favorite field for investigation. Jurassic strata with abundant marine fossils are widely distributed in England, France, Germany, and Switzerland, in easy reach of universities and museums, so that the student of these faunas has an unusual wealth of material at hand. And in this western European province comparatively uniform conditions prevailed during the greater part of this time, allowing the faunas to become widely distributed. It is doubtful if any other succession of fossil faunas in the world is so well known as that of the Jurassic of this province, or if anywhere else such minute stratigraphic and faunal division has been successfully carried out; for there is not a single bed in all the great thickness of Jurassic sediments that does not contain somewhere in this province a rich marine fauna.

Quenstedt devoted his life to a minute subdivision of the Jurassic of Württemberg, establishing a classification that still holds sway in Germany; but this classification was based on local faunas, whose appearance and disappearance were caused by insignificant local changes in sedimentation, and it could hardly be used away from the place where it originated. In this scheme the greater unconformities, overlaps, and faunal changes received no more attention than the smaller geologic events. It was, then, merely a useful local classification, although of great value as a starting point in comparative study.

It was reserved for Albert Oppel,[1] a pupil of Quenstedt, to establish a chronological classification, based entirely on paleontology, and independent of lithologic development. For the entire Jurassic formation Oppel recognized thirty-three zones, or subdivisions characterized by certain species that occurred only in these horizons. The species chosen were of the greatest horizontal and the least vertical distribution, and were usually ammonites. These zones were thought by Oppel to be universal, for he was able to recognize them in Germany, Switzerland,

[1] Die Jura Formation, 1856.

France, and England, and by means of them was able to bring into harmony the local subdivisions already established in these various countries.

This was an important step in the right direction, but experience has shown, since Oppel's time, that these zones were not universal, and could seldom be recognized outside of the province where they were established — not even there always, when there was much difference of facies. So this scheme failed of its immediate purpose, although the final results of it have been more important than Oppel probably ever anticipated.

A further application and enlargement of Oppel's plan has been attempted by Buckman,[1] who has divided the Jurassic formation into *hemerae*, based on the occurrence of certain characteristic species of ammonites. An *hemera* represents a time considerably shorter than a zone, for the Lias, or Lower Jura, alone is divided into twenty-six *hemerae*. These are undoubtedly of much use to the stratigraphic paleontologist in England, probably in France, and possibly in Germany; but these *hemerae* can not possibly be identified away from the limited province where they were established, for in the Alpine or the Austrian Jura one is often lucky to be able to tell whether certain beds belong to Lower, Middle, or Upper Jura. Such finely drawn subdivision is of use only in local stratigraphy.

Buckman further classed a number of *hemerae* together in *ages*, based on the development of a group or series of species; in the Lias alone there are four of these *ages*, which correspond more nearly to the zones of Oppel, but even these could hardly be recognized in southern Europe, and much less in Asia or America.

Oppel thought that his zones were universal, or interregional, but only occasionally can one of them be identified outside of the province where it was named. This is due to the distribution of certain characteristic fossils outside of their usual range, on account of conditions temporarily facilitating interregional

[1] Quart. Jour. Geol. Soc. London. Vol. LIV, 1898. On the Grouping of some Divisions of so-called Jurassic Time.

migrations, which can occur only at times of readjustment of faunal provinces. There can be none in the intermediate periods of stability and quiescence when the fauna is endemic.

The writer proposes to retain the term "zone," in the sense intended by Oppel, as a chronologic term for a limited horizon, or time division, characterized by an interregional fauna. Use of the term in this significance would recognize not only biologic development, but also geologic events, for an interregional fauna can appear only in times of readjustment of biologic regions, of trangressions of the sea on the land, or of opening up connections between regions that before were separated. These are nature's periodic trial balances, during which the geologic columns in various regions, for a while divergent in biologic development and thus in stratigraphic classification, are brought into harmony.

A zone, in this sense, means a comparatively short time in which a certain characteristic, limited group of animals or plants lived—too short for any great faunal change, but long enough for this group to diffuse itself over a great area. To illustrate this let us take a well known example. It must have taken a long time for *Productus semireticulatus* to be dispersed through the seas of Australia, Eurasia, and America, for it is found in all those regions. But no stratigrapher would choose this species as a zone fossil, since it ranges from the Mountain Limestone into the Permian; often characteristic of a certain province during a given time, but of no one horizon everywhere. And during this long time the greater part of the accompanying faunas underwent enormous changes, until most of the genera, even, were new. During all these migrations *Productus semireticulatus* itself underwent modifications until it might be divided into a number of geographic species or varieties, and each of these into mutations or varieties in an upward-ranging genetic series. But accompanying *Productus semireticulatus* there are many species and genera that were short-lived and widely distributed, in some one region appearing as a link in a genetic series, but in some other region appearing sporadically or unheralded by local ancestors, and brought in by immigration

from the outside world. The appearance of such genera or species is an interregional event, and marks an episode in the dynamic history of the earth. Zones are thus not a figment of the stratigrapher's imagination, but are based on geologic events of far-reaching importance, in comparison with which the local shiftings of lithologic facies are insignificant.

Ancient faunal geography.—One of the first things that attracted the attention of naturalists engaged in the study of geographic zoölogy was that animals are not now distributed strictly according to climate, or other physical conditions. Edward Forbes early reached the conclusion that the ancient marine faunal provinces and regions by no means corresponded with the present distribution, and that the present faunal relations could be explained only by study of past geologic changes in the distribution of land and water. The various marine provinces were grouped by S. P. Woodward[1] in great regions: "The tropical and subtropical provinces might naturally be grouped in three principal divisions, viz., the Atlantic, the Indo-Pacific, and the West-American—divisions which are bounded by meridians of longitude, not parallels of latitude. The Arctic province is comparatively small and exceptional; and the three most southern faunas of America, Africa, and Australia differ extremly, but not on account of climate."

What is true of faunal geography today was true of it in the past. While certain faunas, such as the Silurian, have been very widely distributed, on account of the existence then of wide expanses of shallow marginal and epicontinental seas, there were no such things as universal faunas, even in the most remote geologic time. There have always been barriers of continent and ocean, and probably too of climate, ever since life existed on the earth. Only the deep sea faunas could be universal if oceanic basins had been stable; but such faunas are not universal now, nor have they remained unchanged in time.

Many years ago Barrande[2] showed that the Cambrian

[1] Manual of the Mollusca, 1856, p. 353.

[2] Système Silurien du Centre de la Bohême.

deposits known at that time could be grouped in well-defined geographic provinces; it is true that there was a great similarity of animal life in the various regions, but this by no means amounted to identity. Most genera had a wider range then than in later formations, but community of species was as rare in the Cambrian as in the later Mesozoic. Walcott has divided the Cambrian into three great divisions, each named after the most characteristic genus in it: the lower, or *Olenellus* zone; the middle, or *Paradoxides* zone; and the upper, or *Olenus* zone. No one of these had a universal fauna, although certain subdivisions can be traced through several provinces and even regions, and thus deserve the designation "zone," as Oppel used the word. It is noteworthy, too, that these times of interregional distribution come at periods of transgression of the seas on the land, so that a connection between these two phenomena may justly be inferred.

The work of Barrande, James Hall, and Murchison has shown that the Silurian strata and their fossils are as widely distributed as the Cambrian. But during Lower Silurian time the faunas of the American and the European region seem to have been largely endemic. The Trenton sea probably covered the greater part of North America, but only that in the northeastern part of the region shows much relationship to the European. During the Upper Silurian there was considerable readjustment and shrinkage of the sea, and as a consequence of this the Niagara limestone may justly be considered as an interregional zone, although the exact period of the migration cannot be determined.

During the Lower and Middle Devonian the division into regions that had existed in the Silurian still held sway, for it has been shown by H. S. Williams that there was a North-South American and a Eurasian region. But with the beginning of the Upper Devonian the connections had changed so that the grouping was Eurasian-North American, and South American-South African. This change shows itself in North America at the base of the Upper Devonian, where with the *Cuboides* zone

of the Tully limestone there was ushered in a fauna that could not possibly have been developed out of its local predecessors in the Hamilton beds, but whose affinities are with the Upper Devonian of Europe and Asia; in this latter region the *Cuboides* fauna is genetically connected with its predecessors of the Lower and Middle Devonian. In this invasion of the American waters by the *Cuboides* fauna, we have an undoubted zone, the first great interregional migration that can be traced in the history of the earth. But, as has been shown by Professor Williams,[1] this means something more than a mere migration, it means a complete readjustment of the faunal geography of the time. The invasion thus begun was kept up during the succeeding *Intumescens* zone, when Eurasian cephalopods began to make their way from the northwest into the New York[2] province. In these two zones we have divisions that are stratigraphically as well as faunally homotaxial with European beds, that is, they are virtually contemporaneous with them.

The Lower Carboniferous is well known to have beeen a time of extensive encroachment of the sea on the land, in Europe and America, but the boundaries of the sea were not uniform during the various stages of this age.[3] Oscillations within the regions were common, and sometimes they were great enough to allow the influx of an exotic fauna, such as those of the Kinderhook horizon, and of the St. Louis division. On a smaller scale the inter-provincial migrations, or colonies, are known at several different horizons of the Lower Carboniferous, occurring always at a time of expansion of the sea, as in the Burlington division of the Osage, and the St. Louis beds.[4]

The Upper Carboniferous, on the other hand, in the Mississippi valley region of the United States, and in western Europe

[1] The Cuboides Zone and its Fauna, Bull. Geol. Soc. Amer. Vol. I, 1890.

[2] J. M. CLARKE: Naples Fauna, Sixteenth Ann. Rep. New York State Geol., 1898.

[3] S. WELLER: JOUR. GEOL., Vol. VI, 1898, Classification of the Mississippian Series.

[4] H. S. WILLIAMS: Amer. Jour. Sci., Vol. XLIV, 1895, On the Recurrence of Devonian Fossils in Strata of Carboniferous age.

was a time of encroachment of the land on the sea, and only occasionally, when the sea had temporarily reclaimed its own, are marine faunas found in this formation. But when these occur, they are often extra-provincial, and occasionally extra-regional in origin, and thus give a secure basis for correlation with those regions where marine conditions still prevailed. Such a state of affairs existed in western North America and in eastern Europe during the time of the Coal Measures; in these regions the sea transgressed over the land areas, and allowed the marine faunas to become widely distributed. By intermittent subsidence of the low-lying coal swamps an intercalation of marine with freshwater deposits took place, allowing accurate correlation between the two facies.[1] And occasionally these oscillations have been something more than local events, for they have brought in exotic faunas, as in the case of the belated immigration of *Pronorites cyclolobus* and *Conocardium aliforme* in the Lower Coal Measures of America, or the appearance of *Gastrioceras* and *Paralegoceras* in the European waters long after they had appeared in America. The greatest of these disturbances was the Appalachian revolution, which at the beginning of Permian time raised finally above water the continental borders of the old Appalachian land mass, and left only a comparatively small basin for the Permian sea. This rising of the Mississippi valley region was undoubtedly accompanied by sinking elsewhere, for a very similar exotic fauna appeared simultaneously in the American, the European, and the Asiatic region, and mingled with the preëxisting local faunas, giving one of the most distinctive paleontologic zones yet known,

During the Lower Trias the Arctic, the American, and the Oriental regions had closely allied faunas, and might be grouped together in contrast with the Mediterranean. At this time of transgression and readjustment of geographic boundaries we have the widely distributed fauna of the *Meekoceras* zone, distinctly recognizable in India, Siberia, and western America.

[1] J. P. SMITH: JOUR. GEOL., Vol. II, No. 6, 1894, The Metamorphic Series of Shasta County, California.

The Middle Triassic faunas seem to have been largely endemic, because the waters of that time were stable; thus there are no horizons that are directly comparable in distant lands. But again the Upper Trias ushered in a period of transgression and invasion, and the faunal zone of *Tropites subbullatus* appeared simultaneously in the Mediterranean region, in the Himalayas, and in California, with many genera and species common to these countries, exotic in all, and with no previous record to show their origin.

The geographic provinces of Jurassic time have been grouped by Neumayr[1] in two great regions, the Boreal and the Central Mediterranean, and further he has traced out the distribution of climatic zones of that time in the Boreal type, the North Temperate type, the Alpine or Equatorial, and the South Temperate. The western American province belonged to the Central-Mediterranean region and to the North Temperate climatic zone during Lower and Middle Jura, but with the beginning of the Upper Jurassic a great change took place in physical and faunal geography that connected the western American province for a time with the Boreal region. As a consequence of this the faunal zone of *Cardioceras alternans* and *Aucella pallasi* may be traced through Russia, Alaska, and California.[2] The disturbance that caused this invasion may easily be traced in the transgression eastward of the sea on the land that began in northern Europe already in Middle Jurassic, bringing down from the northwest a cold current that permitted the Boreal fauna to make its way into temperate latitudes on the western coast of North America.

The study of the distribution of fossil faunas as influenced by climate was begun by Ferdinand Roemer,[3] who recognized the fact that the Cretaceous of western Europe was similar to that of the Atlantic region in America, and that the faunas of southern Europe, northern Africa, Texas, and Mexico had much in

[1] Denkschr. K. Akad. Wiss. Wien, 1883, Klimatische Zonen während Jura und Kreidezeit.

[2] J. P. SMITH: JOUR. GEOL., Vol. III, 1895, Mesozoic Changes in the Faunal Geography of California.

[3] Kreidebildungen von Texas, 1852.

common. These differences Roemer ascribed to climate, noting that then, as now, the isothermal lines came much further south in eastern America than in Europe.

It has been shown that at the beginning of Cretaceous time the faunal relations of the west coast of North America were still with the Boreal region, as in the Upper Jurassic. But this did not last long, for even before the end of the Knoxville epoch this fauna had died out, and was replaced by immigrants from another region. At first there were only a few stragglers, but soon the rich fauna of the Horsetown stage or Gault made its appearance, of a type precisely like that of southern India, and eastern Africa. A similar association of genera and species is also known in the European region, where it seems to have been endemic, and from which it probably reached the rest of the world by migration. This incursion of exotic faunas marks the last great period of readjustment of the geologic column in various parts of the world, and is therefore of the utmost importance in correlation. The kinship of the western American faunas to the Indian was stronger than that to the eastern American almost until the end of the Cretaceous, when a similarity to the interior province began to show itself. This change culminated in Eocene time, in the zone of *Venericardia planicosta*, when the barrier between the western and the interior Cretaceous provinces was temporarily removed, and through the Atlantic there was direct connection with the European waters. This is the last interregional zone, but it marked an era of retrogression of the sea, rather than of transgression, and since that time the marine provinces and regions correspond closely with the existing boundaries of temperature and shore lines.

Dispersion of marine animals in past and present.—Theoretically, pelagic faunas would be the best means of correlating distant regions; but in all probability we have no fossil pelagic faunas. J. Walther suggests that in the widely dispersed species of Mesozoic ammonites we have virtually a preservation of pelagic animals, or at least that their shells floated after death, and were distributed all over the earth by marine currents. This

sounds plausible, viewed in the light of what we know of the distribution of *Spirula*. But the living Pearly Nautilus is not distributed by currents away from the region of its present habitat, and in studying fossil faunas we find that the cephalopods had little wider distribution than brachiopods and pelecypods, animals usually fixed in station during most of their life, and able to migrate only during the larval stage. Another argument against the current-distribution hypothesis has been brought up by Dr. A. Tornquist, that the fossil ammonites of Jurassic and Cretaceous age are distributed approximately according to climatic zones.

The geologic record has been kept by the inhabitants of submerged continental or island shelves, and their dispersion cannot have been accidental or individual, but was faunal. The means and the reason for this migration are furnished by changes in physical geography. Any rising or sinking of shore lines would drive the inhabitants from their dwelling places; any newly opened connections between regions that before were separated would cause an intermingling of different faunas. An example of this is going on before our eyes today; the Red Sea and the Mediterranean have faunas as distinct as if they occurred on opposite sides of the world, but since the opening of the Suez Canal, intermigration has already begun, and in this present age will be recorded an inter-regional invasion comparable with those that took place in remote geologic time. And no doubt to some future geologist this record will be just as clear as those we have of similar changes in the past. Each great change in the outlines of continents must also have caused great changes in the direction of marine currents. Thus in the great subsidence of land in northern Eurasia that caused the transgression of the Upper Jurrasic sea must have opened the way for the cold current that came from the northwest along the Pacific shore of North America, bringing a Boreal fauna into temperate latitudes. Something similar to this would happen if, at some future time, the old dismembered Antillean continent were raised to its former position; the Gulf Stream could not enter the warm waters

of the Carribean, would be deflected, and the waters of the northwestern coast of Europe would be chilled.

The horizons of America that represent periods of instability of shore lines are the very ones that contain the remains of exotic faunas, such as those of the *Cuboides* zone, the *Intumescens* zone, the Chouteau limestone, the St. Louis beds, or the shifting zones of the Coal Measures. These migrations must all have been faunal rather than individual, and can have been due only to physical agencies acting slowly and on a large scale. No extraordinary catastrophies need be appealed to as an explanation of this, for similar phenomena are always going on before our eyes, in the slow but ceaseless rising of some shores and sinking of others.

Land masses present an insuperable barrier to marine animals; but if the bodies of land are short, and do not reach into polar waters, animals can easily pass around the ends. Thus the molluscan fauna of the Mediterranean does not differ greatly from that of the English waters, because in the passage around the peninsula of Spain, animals remain in temperate waters and under nearly the same conditions. East and west land masses would, therefore, not be effectual barriers, since they would not be so likely to extend into frigid waters nor into very great differences of temperature. An example of this is the similarity of marine faunas on the east and the west coast of Australia.

On the other hand, the Isthmus of Panama separates two faunas absolutely distinct from each other, although in the same latitude, and under the same climatic conditions. Also the Isthmus of Suez separates two totally distinct faunas, but these belong to different regions and even to different climatic zones, brought near together by the narrow strip of the Red Sea. A similar case is known in the Jurassic formation, where the fauna of western Europe stands sharply contrasted with that of Russia; even the characteristic genera are distinct, and this too in latitudes not very different. These two types represent two seas of different climatic zones, separated by a strip of land during the later portion of Jurassic time.

That climatic zones alone are to-day partial barriers to migrants along the coast is shown by the difference in faunas living in northern and in southern latitudes on north-south shores. We would expect cold water species to be able to cross climatic zones more easily than those adapted to warm water. But we know of no cases where equatorial faunas have passed through arctic regions, and even passages from tropical into temperate waters must have been exceedingly difficult, for a fall of a few degrees below the temperature favorable to life must be a great deal more destructive than a rise of many degrees. At present we have no means of testing this statement, but facts brought to light by geology confirm it. The Jura of western Europe and of the Argentine Republic have practically the same fauna, which, in reaching one of these regions from the other, must have passed from temperate waters through tropical, and into temperate seas again. The genera *Lytoceras* and *Phylloceras* are common in the Neocomian beds of southern Europe; but although these waters were undoubtedly connected with those of northern Europe, those genera are lacking in the latter region. Also in the lower part of the Californian Knoxville beds, the above mentioned genera are unknown, and come in only higher up where the first members of the tropical Indian fauna began to appear.

By far the greater part of marine animals live near the shore and are unable to exist under other conditions. To these an abyssal sea is as impassable a barrier as a continent. The marine faunas of the southern ends of Africa, South America, and Australia are in approximately the same climatic conditions, but although they are connected by open seas, they are as different as if they were in totally disconnected basins. But an east-west sea affords good opportunity for passage from one side to the other by slow passage along the margin. The present fauna of the Mediterranean is good evidence of this, the animals of the European shores not differing appreciably from those of the African. The Mesozoic faunas of the ancient Central-Mediterranean sea owe their great distribution to this fact, for nearly the

same conditions existed then as in the present Mediterranean, except that the extent was vastly greater.

And even on opposite sides of great north and south oceans there are usually many species in common; the Atlantic shore American fauna has many European species, and the Pacific shore harbors some from Asiatic waters. Their passage was affected in most cases along continental borders that have since been obliterated by subsidence and erosion. We have an abundance of geologic and biologic evidence that just such changes have taken place in comparatively recent time, for example, the dismemberment of the old Antillean continent since Tertiary time. Also in the Indian Ocean there existed a continent in late Paleozoic and early Mesozoic time, connecting Australia with Asia; and Wallace[1] has shown that even since the Tertiary, Australia has been connected with many of the now separated islands of the Indian Ocean, although cut off even then from Asia.

The occurrence of identical or very closely related species in widely separated localities is good evidence of migration from one of these localities to the other, or from a third region to both. In many cases faunas even appear unheralded by local ancestors; these are exotic, having been brought in by migration from outside regions. In the chapter on paleontologic zones many of these exotic faunas have been enumerated, and the general statement made that their appearance invariably coincides with a time of shifting of the boundaries of land and sea, and consequent opening of new connections.

Colonies.— It is often noticed that species or faunas are intermittent in occurrence, especially when the character of the sediments is shifting. When sands are being deposited in shallow waters certain animals find their favorite habitat there, and when subsidence cuts off the clastic sediments and the waters become clear, other animals hold sway. Such faunal changes are due to the facies of sedimentation, but both sorts lived in the same

[1] Geographical Distribution of Animals, Vol. II, The Australian Region, pp. 387–485.

province and near together. But intermittence of occurrence is occasionally noted when it cannot be due to difference of facies. Just such a case is the reappearance of a Chouteau fauna in the Osage horizon of Missouri,[1] or the reappearance of Devonian types in the St. Louis beds at a number of places in the United States. In the Jura of northern Europe, according to Neumayr,[2] the genera *Lytoceras* and *Phylloceras* appear only sporadically, being lacking in sixteen zones; and even the known species there do not belong to a genetic series. But in southern Europe these genera appear plentifully in all the zones, and seem to represent genetic series. Their migration northward at several successive periods is thus clearly established. In these same beds *Amaltheus* also appears intermittently, but no region is yet known where *Amaltheus* developed continuously. Among the Jurassic ammonites of northern Europe there are a number of other cryptogenic types, many of which coincide with the *Amaltheidae* in their appearance, and thus probably came from the same region.

Today, when the struggle for existence becomes too severe for a species it disappears. In geologic history, too, a species has a certain length of life and dies out, never to reappear. This has given rise to the theory that species, like individuals, have a limited life, and that in time they reach a stage of development where they can go no further, and then of necessity die out. This would all be very well if species dropped out one at a time and contemporaneously all over the earth, but in reality they come and go by faunas. A study of the successive fossil faunas of the Pacific coast region has shown that while there may be a nearly perfect stratigraphic series, the faunal succession is broken, so that each fauna appears unheralded, in a way that would have delighted the heart of Cuvier. But we often find the forerunners of these unheralded faunas in older beds in other regions; this gives the rational explanation of the phenomenon,

[1] C. R. Keys: Amer. Jour. Sci., Dec. 1892, p. 447.

[2] Jahrbuch K. K. Geol. Reichsanstalt, Wien. Bd. 28, 1878. Ueber unvermittelt auftretende Cephalopodentypen in Jura Mittel-Europas.

migration due to the removal of barriers.[1] It would seem, then, that changes in physical geography have been the chief cause, not only of migration, but also of extinction of faunas; and this becomes all the more probable when we reflect that species have not been extinguished contemporaneously over the earth.

Remarkable cases of survivals of types have long been known, as of *Trigonia* in the Australian waters, and of *Pholadomya* in the Antilles. Survivals of faunas, too, are continually coming to light. A number of species that on the west coast of the United States are known only as fossils in Pliocene and Quaternary strata, are still living elsewhere. Dall[2] has shown that a large proportion of the Pliocene and even Miocene invertebrates of the southeastern states are still found living in the archibenthal region off the present coast. Similarly, it has been shown by Walcott[3] that in the Great Basin Carboniferous province many Devonian types persisted long after they had become extinct elsewhere, and this has been used by H. S. Williams[4] to explain the reappearance in the Mississippi valley St. Louis beds of a fauna previously thought to have been extinct since the very beginning of Carboniferous times.

Dr. David Brauns[5] cites from the late Pliocene or early Pleistocene of Japan a large number of species that are still flourishing on the western coast of America, and some are found living there that in western America are known only as fossils. Thus in the future some confusion might originate by correlating these beds with those now forming.

It is well known that during the Upper Carboniferous there flourished in India, South Africa, and Australia the *Glossopteris* flora, a type that in other regions was characteristic of Mesozoic instead of Paleozoic beds. Waagen[6] has suggested that the

[1] J. P. SMITH: JOUR. GEOL. Vol. III, 1895. Mesozoic Changes in the Faunal Geography of California.

[2] Bull. Mus. Comp. Zoöl., Vol. XII, No. 6, p. 186.

[3] Mon. VIII, U. S. Geol. Survey.

[4] Amer. Jour. Sci. III Ser., Vol. XLIX, pp. 94–101.

[5] Mem. Science Dept. Univ. of Tokio, No. 4, 1881, p. 77.

[6] Pal. Indica. Salt Range Fossils. Geological Results, p. 240.

glaciation in this region near the beginning of Permian time killed off the Paleozoic flora and allowed the *Glossopteris* flora to get a foothold earlier than was the case where there was no glaciation. Such phenomena approach the nature of catastrophes, and show that Cuvier's doctrine was not altogether wrong after all, and he probably had something like this in mind, although not formulated. These facts, too, show that the principles on which Barrande's[1] doctrine of "colonies" was founded were right, even though it has since been found that the particular cases on which he based his colonies were only younger rocks carried into the midst of older beds by dislocations. Barrande's idea seems to have been that in certain separated basins a new type of life would be introduced before it appeared elsewhere, and that by changes in physical geography these precursor faunas would be intercalated with those of older type. The modern doctrine of colonies, on the other hand, is that older faunas have often been preserved in places where no great changes have taken place in the conditions necessary for their life, and that these older surviving faunas have been mingled as anachronisms with the younger through immigration made possible by the removal of barriers, or changes in the direction of ocean currents.

Synchronism vs. homotaxis.—Forms are said to be heterochronous when they occur at different horizons, in different regions. Now it is possible that the same species seldom occurs at exactly the same time in two widely separated places; it must originate at the one and migrate toward the other, or migrate to both from a third place. This would take time, and it is supposable that the species might be entirely extinct at the point of origin before it reaches its second habitat, or become so greatly modified on its journey as to require a new name, or a number of new names. A case in point is the migration and development of *Ceratites nodosus* in the middle Trias of Germany. In the North-German basin this species is exceedingly common in the Muschelkalk, and exceedingly variable, but the boldest species-maker has not yet dared

[1] Système Silur. du Centre de la Bohême, Vol. I, p. 73 et seq.

to split it up into a number of species, because there are transitions between all the varieties. Dr. A. Tornquist[1] has recently shown that *Ceratites nodosus* also occurs in the upper Muschelkalk of the southern Alps, and that there the varieties lack the transitions, and thus may be given names to mark this transformation. The immediate varieties never reached the Alpine province, or else the modification took place on the way. The zone of *Ceratites nodosus* is thus inter-provincial in extent.

A somewhat similar case is known in the distribution of certain living species of the genus *Purpura;* in the English waters *Purpura lapillus* is common and exceedingly variable, but no constancy can be traced in these variations, the influence of temperature, sea bottom, and food supply being so evident, and the transitions so gradual that no subdivision of the species is attempted. Some of these same varieties are found on the western coast of America, but without the transitions, and so they are called by a number of specific names, which, although they are given to forms locally distinct, can certainly be only synonyms of *Purpura lapillus.* At some not very distant time these forms migrated westward from the Atlantic waters, and either varied on the journey, or else the intermediate forms did not succeed in reaching the Pacific region.[2] Here is certainly an interregional migration where a species is still living in the waters where it originated.

The genus *Clymenia*, according to J. M. Clarke,[3] appears in the *Goniatites intumescens* zone in New York ; in Europe *Clymenia* is wholly unknown in the *Intumescens* fauna, but is the characteristic form of the next higher division of the Devonian, where the *Intumescens* fauna was already extinct. In North America *Pronorites cyclolobus* and *Conocardium aliforme* appear in the Lower Coal Measures, while they flourished in Europe in the zone of

[1] Zeitschrift d. Deutschen Geol. Gesell. Bd L. Heft 2, 1898, and Heft 4. 1898. Neuere Beiträge zur Geol. und Paläntol. der Umgebung von Recoaro and Schio (im Vicentin).

[2] A. H. Cooke, Mollusks, 1895, pp. 90 and 363.

[3] Am. Jour. Sci., Ser. 3, Vol. XLIII, p. 57.

Goniatites striatus of the Mountain Limestone. The genera *Gastrioceras* and *Paralegoceras* appeared in America in the zone of *Goniatites striatus*, while they are not known in Europe before the Coal Measures. But the accompanying faunas in these regions are, in the main, correlative, and so the heterochronous appearance can be detected.

In the Upper Trias, Karnic stage, of California *Halorites* occurs, although in both the Alps and the Himalayas it is characteristic of the higher Noric stage. Also in California *Trachyceras* and *Protrachyceras* occur in the zone of *Tropites subbullatus*, mingled in the same hand specimen with typical species of the *Subbullatus* fauna; in the Alps and in the Himalayas *Trachyceras* and *Protrachyceras* are older than the *Subbullatus* zone, and are never found in it.

Now, when we have fossil species or short lived genera common to two regions, are the strata of these regions to be considered as synchronous? Huxley[1] advanced the theory that migration from one region to another would consume so much time that a fauna might become extinct in one region before it reached the other, and that since we determine the age by these faunas, the time of deposition of strata assigned to the same geologic age might be very different. Thus a Silurian fauna might survive in one region, while a Devonian fauna flourished in a second, and a Carboniferous fauna might be beginning in a third region. But the fossiliferous beds are Silurian, or Devonian, or Carboniferous in the faunal sense. This relation Huxley called *homotaxy*, and most geologists have accepted without question the validity of the hypothesis.

Viewed in the light of modern distribution of fauna, there must be something in it. The present Australian fauna is often cited as an example of unreliability of the time scale when based on faunas, as a survival of Quaternary life at the present time; it certainly is peculiar, for the continent has been totally cut off from other regions since early Mesozoic time. This fauna, however, has not dropped behind; it has gone on specializing in

[1] Presidential address. Quart. Jour. Geol. Soc. London, 1862. Vol. XVIII.

Table of Interregional Zones

		Europe	North America	Asia
Tertiary	Pliocene			
	Miocene			
	Eocene	Zone of Venericardia planicosta	Atlantic Slope, Gulf Region California and Oregon	
Cretaceous	Upper	Zone of Hippurites	Texas and Mexico	
		Zone of Schloenbachia	West coast and Interior	India
	Lower	Zone of Acanthoceras mamillare	West Coast	India
		Zone of Aucella terebratuloides	California and Alaska	Siberia
Jurassic	Upper	Zone of Cardioceras alternans	California	India and Siberia
	Middle			
	Lower	Zone of Arietites	Nevada and California	Japan and Island of Rotti in the Indian Ocean
Triassic	Upper	Zone of Tropites subbullatus	California	India
	Middle	Zone of Ceratites and Beyrichites	Nevada	India and Siberia
	Lower		Zone of Meekoceras boreale in California and Idaho	Siberia and India
Carboniferous	Permian	Zone of Medlicottia in Sicily and Russia	Texas	India and China
	Coal Measures	Zone of Gastrioceras marianum	Mississippi Valley and Texas	? Beds of Lo Ping China
		Zone of Gastrioceras listeri	Mississippi Valley	
		Zone of Glyphioceras beyrichianum	Arctic America	Sumatra ?
	Lower Carboniferous	Zone of Goniatites striatus	Mississippi Valley and Texas	
		Zone of Productus giganteus in Russia and Belgium	California	Siberia and China
		Zone of Aganides rotatorius	Mississippi Valley	
Devonian	Upper	Zone of Manticoceras intumescens	New York	Siberia ?
		Zone of Rhynchonella cuboides	New York	Siberia
	Middle			
	Lower			
Silurian	Upper	Zone of Calymmene blumenbachi	Mississippi Valley and New York	
	Lower			
Cambrian	Olenidian	Olenus fauna	Canada	
	Paradoxidian	Paradoxides fauna	United States and Canada	
	Olenellidian	Olenellus fauna	United States and Canada	

its own lines, and in all the geologic ages to come will never reach the development of life as we know it elsewhere in the Era of Man.

But is the marine fauna on the Australian shores markedly different from that in other parts of the Indian Ocean, and has that of the Indian Ocean no near relationships with the outside world? There are faunal provinces in these, with local characteristics, but with gradual transition from one province to another, and from one region to another through adjacent provinces. Thus the Australian waters show a gradual transition in fauna to the China Sea, and that to the Japanese marginal fauna, which, in turn, show many species in common with the west American region.

If, then, the modern Pacific and Indian Ocean marginal faunas were fossilized it would be no great task to correlate them, although the western coast of America might not show a single species in common with Australia. The laws that govern the distribution and intergradation of marine faunas are the same now as they have always been. All stratigraphic classification and all paleontologic correlation are based ultimately on fossil marine faunas.

The reality of correlation.—The geologic succession of faunas has some irregularities and anomalies, as shown above, but the displacements of the time scale are too slight and the uniformity in various separated regions too great to lay much stress on homotaxis as opposed to synchronism. While homotaxial strata are not necessarily synchronous in years nor in centuries, the cases cited above show that they often are actually contemporaneous. But even if they were not, years and centuries count little as compared with the time back to the Quaternary, and still less with the great stretches of time in the Paleozoic. And if a Silurian fauna still persists beyond its time by reason of local favoring conditions, it is merely a transient exception, for interregional migration soon readjusts the faunal scale in harmony with the time scale. The survivals of species or faunas are the exception rather than the rule, and such anachronisms can be detected in the past as well as now.

If there had ever been any great displacement of the faunal scale from the time scale, this would have been cumulative, and eventually the paleontologic column of America would have been out of harmony with that of Europe. But the successive faunas from Lower Cambrian to Pleistocene are in perfect accord in all the regions of Europe, Asia, Africa, America, and Australia; there are constantly recurring small displacements due to temporary isolation, and constantly recurring readjustment due to reopened or newly-formed connections, giving interregional correlative faunal zones through migration. These zones may be, and often are, actually synchronous. The periods of endemic development may be homotaxial, but the zones of readjustment are correlative in the strictest sense.

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CONTRIBUTIONS FROM WALKER MUSEUM. I.

THE VERTEBRATES FROM THE PERMIAN BONE BED OF VERMILION COUNTY, ILLINOIS.

THE material described and figured in the present contribution comprises a portion of the vertebrate material of the Gurley Collection of Fossils in the Walker Museum, at the University of Chicago. The material is of extreme interest from both an historical and a scientific standpoint, its discovery being the first evidence of the occurrence of Permian reptiles in North America. A few isolated bones were submitted to Professor Cope, and with his usual keen insight he recognized their character and their value, and by his interest he stimulated the work of their careful collection and preservation. To Mr. Gurley is due the credit for a careful and exhaustive exploration of the "bone bed," and the preservation of the material.

Many of the forms were described by Cope in the files of the Proceedings of the Philadelphia Academy of Natural Science, and the American Philosophical Society, but only a few illustrations of the intercentra of *Cricotus* have ever been published. It was his intention to publish full descriptions of the forms, with illustrations, and for this purpose plates had been prepared for an article in one of the government publications, which was never issued. Much of the material is fragmentary, and nearly all the bones were found isolated, so that it is especially difficult to identify the species from the descriptions alone. Especially is this true when the specimens to be compared come from another locality.

In the present paper the original descriptions have been reproduced, wherever they would serve the purpose, along with some additional notes, and the specimens figured. In many instances the figures have been copied from those prepared by Cope for his unpublished work. A few of the specimens

described by Cope are now missing from the collection, and so cannot be figured.

Several specimens are preserved in the collection which were never described by Cope. I have refrained from giving new names to these, as it is altogether probable that the seemingly new forms are but portions of the skeleton of animals that have been named from other parts of the skeleton. The numbers given at the close of each description, are the record numbers of the Paleontological collection in Walker Museum, at the University of Chicago.

Janassa strigilina Cope. Plate I, Figs. 1*a*, 1*b*, 1*c*.

Strigilina linguæformis Cope, 1877, Proc. Am. Phil. Soc., p. 53. (Specific name preoccupied in 1868 by Atthey.)

Janassa strigilina Cope, 1881, Am. Nat., p. 163.

Janassa strigilina Woodward, 1889, Cat. Foss. Fishes Brit. Mus., Pt. I, p. 38.

Generic characters: "The tooth is a flat, osseous plate, whose outline is pyriform, the wider end recurved in one direction as the transverse cutting edge; the other extremity narrowed and recurved in the opposite direction as the root. The side from which the cutting edge arises is crossed by numerous plicæ from the base of the root to near the base of the cutting edge; the opposite side is smooth."

Specific characters: "The plicate surface terminates behind in a median angle, at the base of the root. There are eight plicæ which all cross the plane, excepting the sixth, which is interrupted in the middle by the strong angulation of the seventh, which touches the fifth. The lateral extremities of the right are in contact with the base of the recurved cutting portion. The latter is convex transversely, leaving a smooth surface between it and the eighth plica. The smooth side of the tooth is shining, and there is a shallow fold, which passes around its side and crosses just at the base of the recurved cutting lamina."

MEASUREMENTS.

"Total length of the plane - - - - - -	.008 m
Width at base of the cutting lamina - - -	.006
Width at the base of the root - - - - -	.004
Thickness of plane portion - - - - -	.0015 "

[No. 6500.]

Janassa gurleyana Cope. Plate I, Figs. *2a*, *2b*, *2c*.

Strigilina gurleiana Cope, 1877, Proc. Am. Phil. Soc., p. 191. (Pal. Bull., No. 26.)

Janassa gurleiana Cope, 1881, Am. Nat., p. 163.

Janassa gurleiana Woodward, 1889, Cat. Foss. Fishes Brit. Mus., Pt. I, p. 39.

"The tooth is quite small, its length only equaling the width of the known tooth of *S.* (*Janassa*) *linguæformis*. It is also narrower in proportion to the length. The root and the cutting edge are turned in opposite directions as in the other species. The principal difference between the two is seen in the character of the transverse ridges or crests of the oval face. There are two crests less, or five, with a delicate basal fold, making six, while, counting the fold, there are eight in *S.* (*Janassa*) *linguæformis*. The anterior ridge is transverse; the others slightly convex backwards, and all are equidistant and uninterrupted, which is not the case in the older species. They are also of different form, being distinct ridges with anterior and posterior faces similar. In *S.* (*Janassa*) *linguæformis* the anterior face only is vertical, the posterior descending very gradually, the whole forming a series of steps.

"Length of the ridged face, $.0060^{m}$; width anteriorly, $.0035^{m}$; width posteriorly, $.0020^{m}$."

[No. 6501.]

Pleuracanthus (Orthacanthus) quadriseriatus Cope. Plate I, Figs, *3a*, *3b*.

Orthacanthus quadriseriatus Cope, 1877, Proc. Am. Phil. Soc., p. 192. (Pal. Bull., No. 26.)

Pleuracanthus quadriseriatus Woodward, 1889, Cat. Foss. Fishes Brit. Mus., Pt. I, p. 9.

Represented in the collection by imperfect radial spines. Both Newberry and Cope remark that it is very likely that the spines called *Orthacanthus* may belong to the the same fish as the teeth called *Didymodus* (*Diplodus*), and as the teeth are distinctly referable to the genus *Pleuracanthus Ag.*, it is perhaps best to follow Zittel in regarding all three names as synonyms of *Pleuracanthus*. The teeth and spines are found in close connection. The species here described differs from the *O. gracilis* of Newberry in having the denticles shorter. The description given by Cope is as follows: "The spine is wider than deep, and the series of denticles are widely separated. The surface between them is gently convex and smooth. The anterior face is strongly convex, and presents at each side two shallow furrows. The external groove is divided by a series of thin longitudinal denticles which are smaller than those of the principal row, and which are

sometimes confluent at the base. The principal denticles are closely placed, stout, acute, and recurved.

"Transverse diameter of shaft .0035^m; antero-posterior diameter .0025^m; the portion of the shaft preserved is straight."

It is noticeable that the denticles of the outer row become confluent in a low ridge on the lower portion of the spine.

[No. 6502.]

Pleuracanthus (Orthacanthus) gracilis Newb. Plate I, Fig. 4.

Orthacanthus gracilis Newb., Geol. Surv. Ohio, Pal., Vol. II, p. 56. Plate LIX, Fig. 7.

Orthacanthus gracilis Newb., Cope, 1881, Am. Nat., p. 163.

"Spine small and straight, about three inches long, very slender and acute; section circular at base, posterior face and sides flattened above, the angle inclosed by them set with acute, recurved, compressed denticles throughout the upper two thirds of the entire length; surface smooth or finely striate longitudinally."

The name *Orthacanthus* was used by Newberry only provisionally for spines which were supposed to belong with teeth called *Diplodus*, and was to be suppressed when the two should be found together.

It is noticeable that the denticles are fewer and larger than those on the spine of *P. quadriseriatus*, and that there is but a single row of denticles on each side.

[No. 6503.]

Pleuracanthus (Didymodus) compressus Newb. Plate I, Figs. 5*a*, 5*b*, 5*c*, 5*d*.

Diplodus (?) *compressus* Newb., Cope, 1877, Proc. Am. Phil. Soc., p. 54.

Didymodus (?) *compressus* Newb., Cope, 1883, Proc. Phil. Acad. Nat. Sc., p. 108.

Represented in the collection by several imperfect teeth. Cope offered no additional description of the form, contenting himself with the statement that "one with a lateral and median denticles nearly complete, agrees pretty well with the species cited." In 1883 he substituted the name *Didymodus*, as the name *Diplodus* was preoccupied, having been used by Rafinesque for a genus of fishes.

The teeth are much smaller than the species of the same genus found in Texas.

Later several complete crania of the genus were obtained from Texas and described in detail by Professor Cope, Trans. Am. Phil. Soc., 1884, pp. 572–590, 1 plate (Pal. Bull., No. 38). In the American Naturalist of the same year, p. 413, the genus was made the type form of the new order *Ichthyotomi* of the *Elasmobranchii.*

The form is now quite usually recognized as belonging to the genus *Pleuracanthus* Ag., one of the common forms of the Carboniferous and Permian faunas of Europe and America.

[No. 6504.]

Thoracodus emydinus Cope.

Thoracodus emydinus Cope, 1883, Proc. Acad. Nat. Sc., Phil., p. 108.

Thoracodus emydinus Woodward 1889, Cat. Foss. Fishes Brit. Mus., Pt. I, p. 39.

"The form of the tooth or jaw on which this genus is proposed, reminds one of that of a *Diodon*, and also of one half of that of a *Janassa.* It appears to be the half of a bilateral plate, which is divided on the middle line by suture. Its form is somewhat that of the anterior part of an episternal bone of a tortoise. It consists essentially of a smooth border, separated from the remainder of the tooth by a transverse groove. The interior portion is, on the superior face (if the piece belong to the inferior jaw, and *vice versa*), transversely ridged and grooved, after the manner of the genus *Janassa.*"

Specific characters: "The smooth border is wide above and below. Its edge is produced into a median projection, which is decurved. On the inferior surface it is marked by shallow grooves, which radiate from the groove which bounds it posteriorly, extending nearly to the free edge. Posterior to the bounding groove, the surface is smooth. The posterior surface above has its grooves concentric with the curved free margin. The ridges are narrow, and step-like in position, presenting their free edges backwards. There are no grooves other than these steps. They have an angular curve opposite to the angle of the free margin, and at the angle the groove which separates them is narrowed, while it widens at other points. Free edge of border thickened; surface everywhere smooth."

MEASUREMENTS.

"Length of fragment transversely - - - -	.014^{m}
Length of fragment antero-posteriorly - -	.011
Width of border area at median suture - -	.005
Seven cross ridges - - - - - - -	.005
Thickness at suture at cross ridges - - -	.002 "

[This specimen is missing from the collection.]

Sagenodus vinslovii Cope. Plate I, Figs. 6*a*, 6*b*.

Ceratodus vinslovii Cope, 1875, Proc. Phil. Acad. Nat. Sc., p. 410.

Ceratodus vinslovii Cope, 1877, Proc. Am. Phil. Soc., p. 54.

Ptyonodus vinslovii Cope, 1877, Proc. Am. Phil. Soc., p. 192. (Pal. Bull., No. 26.)

Sagenodus vinslovii Woodward, 1891, Cat. Foss. Fishes Brit. Mus., Pt. II, p. 262.

Sagenodus vinslovii Williston, 1899, Kans., Univ. Quart., Series A, p. 176.

"The crown of the tooth is in general outline an oval, wider at one end than the other, the inner border gently convex and entire. The outer border is marked by six shallow notches which are separated by as many sharp, compressed projections. The emarginations and denticles are the termini of corresponding grooves and ridges, which radiate from a smooth space along the inner margin of the crown. From this plane the grooves gradually deepen to the margin; the separating ridges are acute and without irregularity or serration. The base or root of the tooth is quite wide. Externally it extends beyond the border of the crown at the notches, and has projections corresponding to the denticles, from which it is separated by a horizontal notch. On the inner side the base extends like a shelf beyond the posterior half of the crown, and is produced backwards beyond its posterior border. The inferior plane is concave in transverse section; the crown is plane in all directions."

MEASUREMENTS.

"Length of crown preserved - - - - - -	.021^{m}
Width crown - - - - - - - -	.013
Length of root preserved - - - - -	.022
Depth of root internally - - - - - -	.005
Depth of root externally - - - - -	.003 "

"This *Ceratodus* (*Ptyonodus*) resembles the species described by Agassiz under the name of *C. parvus* and *C. serratus* from the English Trias, but differs from them in the shortness of the tooth-like processes. In none of the species do I find such a development of the basis on the inner side."

[No. 6507.]

Sagenodus vabasensis Cope. Plate I, Fig. 7.

Ctenodus vabasensis Cope, 1883, Proc. Phil. Acad. Nat. Sc., p. 110.

Sagenodus vabasensis Woodward, 1891, Cat. Foss. Fishes Brit. Mus., Pt. II, p. 261.

Sagenodus vabasensis Williston, 1899, Kans. Univ. Quart., Series A, p. 176.

"This fine species is represented by an almost perfect tooth. It is allied to the *C. fossatus* Cope, but is wider, and the crests do not radiate so equally, but are chiefly directed in one direction, as in most species of the genus. The *C. gurleianus* and *C. pusillus* are at once distinguished by the small number of crests, while the *C. periprion* and *C. dialophus* have a larger number of crests, and are otherwise different. *C. porrectus* differs less from it, but has only five $\frac{1}{1}$ crests, while *C. vabasensis* has six $\frac{1}{1}$. The $\frac{1}{1}$ represents the small posterior (?) crest, which is double. This, with the next one, is directed slightly posteriorly; the fifth is at right angles to the long axis, and the anterior four extend more or less forwards. They are serrate nearly to their bases, but the teeth are obsolete on their basal halves. The straight part of the internal edge extends as far forwards as the fourth crest, and is continued posteriorly as a short process. No fossæ at ends of crests. Superior face of tooth wide and slightly concave. The anterior part of the first and second crests are broken away, so that it is impossible to say whether they are produced as in *C. porrectus*."

MEASUREMENTS.

"Length to marginal base of second crest	.024^{m}
Width at marginal base of second crest	009
Width at fourth crest, inclusive of apex	.015
Width of posterior side	.010
Thickness at base of fifth crest	.005 "

[No. 6510.]

Sagenodus gurleyanus Cope. Plate I, Figs. 8*a*, 8*b*, 8*c*.

Ctenodus gurleyanus Cope, 1877, Proc. Am. Phil. Soc., p. 55.

Sagenodus gurleyanus Woodward, 1891, Cat. Foss. Fishes Brit. Mus., Pt. II, p. 261.

Sagenodus gurleyanus Williston, 1899, Kans. Univ. Quart., Series A, p. 176.

"This species is indicated by a portion of a tooth, which leaves the number of the ridges a matter of uncertainty. On this account its description might have been postponed, but that the distinctness of its characters render it clear that it cannot be placed with any other species. The crown, as in *Ceratodus* (*Sagenodus*) *paucicristatus*, is narrow and rather thick; but three

crests are present, all radiating in the same general direction, the longer close to the inner border. There was not more than one additional crest, or one and a rudiment, and these have probably the same direction as those which are preserved. The crests are sharp, elevated, and coarsely dentate; they are not decurved at the extremity, but cease abruptly with a projecting denticle, beneath which the basis is excavated by a shallow fossa. The inferior face is slightly concave, the internal wall vertical."

MEASUREMENTS.

"Greatest width	$.008^m$
Depth at inner border	.005 "

[No. 6509.]

Sagenodus pusillus Cope. Plate I, Figs. 9*a*, 9*b*.

Ctenodus pusillus Cope, 1877, Proc. Am. Phil. Soc., p. 191. (Pal. Bull., No. 26.)

Sagenodus pusillus Woodward, 1891, Cat. Foss. Fishes Brit. Mus., Pt. II, p. 261.

Sagenodus pusillus Williston, Kans. Univ. Quart., Series A, p. 176.

"Form narrow, the width of the base about equal to the depth. The coronal portion is narrower than the base, because the inner face is oblique, forming an acute angle with the inferior plane. There are but four crests, of which the two longer are directed in one direction, and the two shorter in another. The interior ones of both pairs form a continuous crest which is convex inwards. The crests are straight, elevated and acute; each one supports two or three denticles, which are rectangular and little elevated. The longer ones project beyond the general outline; the shorter ones are less prominent at the extremities; all are obtuse in the vertical direction. The superior surface is smooth. The inferior is slightly concave in the transverse sense. The tooth on which this species is founded is the smallest yet obtained from the formation (Permian of Illinois). Length, $.007^m$; width, $.003^m$; depth at the inner crest, $.003^m$."

[No. 6508.]

Sagenodus fossatus Cope. Plate I, Figs. 10*a*, 10*b*.

Ctenodus fossatus Cope, 1877, Proc. Am. Phil. Soc., p. 54.

Sagenodus fossatus Woodward, 1891, Cat. Foss. Fishes Brit. Mus., Pt. II, p. 261.

Sagenodus fossatus Williston, 1899, Kans. Univ. Quart., Series A, p. 176.

"Represented by a nearly perfect tooth of a general narrow and vertically thickened form. There are five crests, the largest three extended in one

direction, and the other two in the other. Between the last of the latter and the inner border is a rudiment of another in the form of a rugosity. None of the crests touch each other at their bases. At their extremities they curve rather abruptly downward, and do not project beyond the inferior plane, from which each one is separated by a deep fossa, whose mouth is a notch in its base. The crests are coarsely dentate, there being three or four teeth on each, and the grooves between them are marked by coarse transverse undulating grooves. The inner border is a deep vertical plane; the inferior face is narrow and concave in transverse section."

MEASUREMENTS.

"Total length - - - - - - -	.022^{m}
Greatest width - - - - - -	.007
Depth at middle - - - - - -	.006 "

"It differs from the *C. serratus* of Newberry in its narrow form, small number of ridges and the very slight prolongation of their extremities."

[No. 6506.]

Sagenodus heterolophus Cope.

Ctenodus heterolophus Cope, 1883, Proc. Acad. Nat. Sc., Phil., p. 109.

Sagenodus heterolophus Woodward, 1891, Cat. Foss. Fishes Brit. Mus., Pt. II, p. 261.

Sagenodus heterolophus Williston, 1899, Kans. Univ. Quart. Series A, p. 176.

"This species is represented by a single broken tooth, which presents remarkable characters. It had apparently, when perfect, but three crests, which differ greatly in length, diminishing very rapidly from the first or marginal crest.

"The crest just mentioned is not only longer, but *much more* elevated than the others, except at the base, where the second crest is the highest. But while the first rapidly rises, the second retains its elevation, and then descends, forming a convex edge, of which the distal part is obtusely serrate. The proximal part of the first crest is worn by friction with the opposing edge of the opposite jaw into a sharp edge, below which its base is covered by a thin layer of the shining cementum which invests the teeth and sides of the second crest. The amount of this shinning layer is thus more extensive than in any other species of *Ctenodus* known to me. The third crest, judging by its base of continuity with the second, is very small."

MEASUREMENTS.

"Elevation of first crest at middle - -	.0095^{m}
Elevation of second crest at middle - -	.0065
Length of a tooth of second crest -	.0020 "

[This specimen is missing from the collection.]

Sagenodus paucicristatus Cope. Plate I, Figs. 11*a*, 11*b*.

Ceratodus paucicristatus Cope, 1877, Proc. Am. Phil. Soc., p. 54.

Ptyonodus paucicristatus Cope, 1877, Proc. Am. Phil. Soc., p. 192. (Pal. Bull., No. 26.)

Sagenodus paucicristatus Woodward, 1891, Cat. Foss. Fishes Brit. Mus., Pt. II, p. 261.

Sagenodus paucicristatus Williston, 1899, Kans. Univ. Quart., Series A, p. 175.

"The single tooth representing this species is narrow in the transverse direction, but stout in vertical diameter. But four ridges are present, all of which have a single direction, but the shorter ones are the less oblique to the long axis of the tooth. They all extend into the inner border but become low as they approach it. Distally they are quite prominent, but do not project very far beyond the emarginate border between them. The inner border is plane and vertical, and without ledge; the inferior surface is concave in the transverse direction. The surface of the tooth is minutely and elegantly corrugated."

MEASUREMENTS.

"Length from the base of second rib - - -	.017 m
Depth at base of second rib - - - - -	.0045 "

[No. 6505.]

Peplorhina arctata Cope.

Peplorhina arctata Cope, 1877, Proc. Am. Phil. Soc., p. 55.

Theromorphous Saurian, Proc. Am. Phil. Soc., 1882, footnote to p. 461. (Pal. Bull., No. 35).

The species was based on an imperfect bone bearing small teeth. From its resemblance to the palatal teeth of *Peplorhina anthracina* the author refers it to that genus with the remark that "this course is open to modification should subsequent investigation require it." Later, in 1882, he remarks in a footnote; "*Peplorhina arctata* Cope from the Illinois Permian is not a *Peplorhina* but a *Theromorphous Saurian*."

The broken specimen originally described certainly has much the appearance of the small teeth which occur in the roof of the mouth of certain of the *Cotylosauria* and may very possibly belong there, but there is present in the collection a complete plate showing no sutural edges. It is certainly a plate from the mouth of a *Crossopterygian* fish, and as the description of the perfect portions of Cope's specimen applies very perfectly to it, it may best be considered under the original name. The applicable portion of the original description is as follows: "The convex surface (of the plate) is thickly

studded with teeth, which are not in contact with each other. Their size increases from one side of the bone to the other, and still more, from one extremity to the other. The crowns are swollen at the nearly sessile base, and contract rapidly to a conical and unsymmetrical apex. One side of the latter is slightly concave below the apex. The surface is shiny and distinctly grooved. Fractured crowns do not display any central cavity."

The present specimen is rather oval, one side showing a perfect convex outline and the other with three straight edges at large angles to each other. The whole plate is convex on the toothed side and concave below. The angulated border is thickened and roughened and the rounded border thin. The surface is covered with teeth, larger in the middle and on the thickened border than on the other edges. The plate is .0158^{m} long and .0114^{m} wide.

[Nos. 6511 (Cope's type) and 6512.]

Cricotus heteroclitus. Plate I, Figs. 12*a*, 12*b*, 12*c*, 12*d*, 13, 14.

Cricotus heteroclitus Cope, 1875, Proc. Phil. Acad. Nat. Sc., p. 405.

Cricotus heteroclitus Cope, 1877, Proc. Am. Phil. Soc., p. 64.

Cricotus discophorus Cope, 1877, Proc. Am. Phil. Soc., p. 186. (Pal. Bull., No. 26.)

Cricotus heteroclitus Cope, 1878, Proc. Am. Phil. Soc., p. 522. (Pal. Bull., No. 29.)

The genus was founded on some intercentra which were regarded as centra of the caudal region; it was not until 1878 that the true nature of the intercentra was made out. With the intercentra were a few other bones doubtfully referred to the same genus. That portion of the original description which is applicable to the bones as intercentra is as follows: "The caudal vertebra (intercentrum) best preserved is stout, discoidal in form, and deeper than wide. It resembles in form that of an herbivorous dinosaurian, but differs otherwise. The articular faces are deeply concave, the posterior most strikingly so; and the middle is occupied by a large foramen, whose diameter is about equal to that of the centrum on each side of it. The lateral borders of the posterior articular face are expanded backwards, and articulate with a bevel of the corresponding edge of the anterior articular extremity. In this way the vertebra combines the mechanical relations of the biconcave with opisthocœlian structures. These neural arches (hæmapophyses) are narrow and directed backwards; their bases are firmly coössified with the centrum." . . . . "On the inferior (superior) surface of the centrum (intercentrum) two shallow pits occupy considerable space. . . . ." It will be noticed that the describer had the intercentrum inverted; this fact was later understood by himself and certain drawings corrected. The structure of the skull and other

portions of the skeleton of the species are described by Cope in the Proc. Am. Phil. Soc., 1878, p. 523 and figured in the same, 1882, Plate II. The synonymy of *C. heteroclitus* and *C. discophorus* was also recognized by Cope in Proc. Am. Phil. Soc., 1878, p. 523.

[No. 6517 (the type specimen), 6518 (type of *C. discophorus*), 6519, and 6520].

Cricotus gibsoni Cope, Plate I, Figs. 15*a*, 15*b*, 15*c*.

Cricotus gibsoni Cope, 1877, Proc. Am. Phil. Soc., p. 185. (Pal. Bull., No. 26.)

Represented in the collection by several vertebræ, all of one form. Cope considered the type specimen as probably from the caudal region. He says, "On this vertebra there is no trace of diapophysis, and the neurapophysis rises from the external side of the superior face. The wall of the neural canal is not preserved, but the inference is that the diameter of the latter is large. This fact and the absence of definite chevron articulations leads me to doubt the caudal position of the vertebra; but the usual marks of the dorsal and cervical vertebrae are totally wanting from it. As in *C. heteroclitus*, the *foramen chordæ dorsalis* is large, its diameter being one third of the total. The articular faces descend steeply into it, that of one extremity more so than the other. The rim of the latter face is beveled outwards, the plane thus produced appearing on the inferior face something like the united faces of the chevron bones.

"The centrum is a little deeper than wide, and the inferior face is truncate so as to give a subquadrate outline. The inferior plane is concave, the concavity being divided by a longitudinal rib. The sides are somewhat concave, with a longitudinal rib at the middle. Diameters of centrum: vertical .010^m; transverse .009^m; longitudinal .008^m. Width of inferior plane .005^m; width above, including neurapophyses .008^m.

"As compared with *C. heteroclitus* this species differs in the presence of parallel ridges inclosing a median fossa on the inferior side of the centrum. The small size may be considered, but it is uncertain whether the two animals represented by the vertebrae are fully grown."

[Nos. 6521 and 6522.]

Cricotus sp. Plate V, Figs. 13*a*, 13*b*, 14*a*, 14*b*, 15, 16.

There are several phalanges of *Cricotus*. They are much stouter than those of *Clepsydrops;* even in the members of the distal series, where the phalanges are very short, they are still very stout, almost as broad as long. They show a delicate sculpture over the entire surface; the articular surfaces are less well defined than in the reptilian forms. In the middle series they

are longer in proportion than at either end, rather curved, flattened, and with the shaft little less in width than the extremities.

[No 6523.]

Diplocaulus salamandroides Cope. Plate I, Figs, 16*a*, 16*b*, 17*a*, 17*b*. Plate V, Figs. 17*a*, 17*b*, 17*c*, 17*d*.

Diplocaulus salamandroides Cope, 1877, Proc. Am. Phil. Soc., p. 187. (Pal. Bull., No. 26.)

Diplocaulus salamandroides Cope, 1882, Proc. Am. Phil. Soc., p. 451. (Pal. Bull., No. 35.)

Cope's generic description is as follows: "Vertebral centra elongate, contracted medially, and perforated by the foramen chordæ dorsalis; coössified with the neural arch, and supporting transverse processes. Two rib articulations one below the other, generally both at the extremities of the processes, but the inferior sometimes sessile. No neural spines nor diapophysis; the zygapophyses normal and well developed."

Specific description: "The surface of the centrum is smooth and is without grooves. The diapophyses and parapophyses are rather elongate, and are closely approximated one above the other. The superior process issues from the centrum opposite the superior margin of the articular faces. They stand equidistant from the extremities of the centrum, and are directed obliquely backwards. The anterior zygapophyses occupy the same level. The neural spine is a compressed longitudinal ridge; it divides behind, leaving a notch between the posterior zygapophyses."

MEASUREMENTS.

"Diameter of centrum	longitudinal	$.0060^{m}$
	vertical	.0025
	transverse	.0025
Depth of centrum and neural arch		.0060
Width with transverse processes		.0070
Expanse of posterior zygapophyses		.0050 "

A portion of a small skull was in contact with one of the vertebra. The ramus of the jaw is shallow and stout, the external surface sculptured with inosculating lines. Teeth with cylindrical roots set in shallow alveoli. The crowns elongate, slightly compressed near the apex, and without grooves or lines.

In describing the vertebræ of *D. magnicornis* from Texas (Proc. Am. Phil. Soc., 1882, p. 453) Cope calls attention to the presence of zygosphene and zygantrum in that species; they are also present in the *D. salamandroides*, but are so small as to easily escape notice. The surface of the centrum is stated to be smooth in the Illinois species, this is largely due to weathering, as the more perfect specimens show the same beautiful sculpture as in the Texas forms,

The articulations for the ribs are separate in the cervical region, and become more and more closely united posteriorly. The resemblance between *D. salamandroides* and *D. magnicornis* is very striking, almost the only observable difference being in the size, the latter being from five to six times the size of the former. This statement is limited to the vertebral column, as the skull of the Illinois species is unknown.

In the Proceedings of the Am. Phil. Soc., 1882, p. 452 (Pal. Bull., No. 35), Cope gives a history of the classification of *Diplocaulus* and a summary of the characters of the genus as derived from specimens from the Permian of Texas.

[Nos. 6513, 6514, 6515, and 6516.]

Clepsydrops colletii Cope. Plate II, Figs. 1*a*, 1*b*, 1*c*, 2*a*, 2*b*, 3*a*, 3*b*.
Clepsydrops colletii Cope, 1875, Proc. Phil. Acad. Sc., p. 407.
Clepsydrops colletii Cope, 1877, Proc. Am. Phil. Soc., p. 62.

This genus was based on a series of vertebræ supposed to represent the cervical caudal and dorsal regions. With them were associated other bones, which in all probability did not belong to the same specimen, though they may have belonged to the same species of the genus. The vertebræ were compared with those of the *Cricotus*, or rather with the intercentra of *Cricotus*, as Cope was not entirely sure at the time of the amphibian nature of *Cricotus*. The original description of the vertebræ given by Cope to characterize the genus *Clepsydrops* is as follows: "They are deeply biconcave, the articular cavities being funnel-shaped and continuous, thus perforating the entire length of the centrum. In a dorsal vertebra the cavities communicate by a very small orifice, while in the posterior the median contraction of the canal is less marked. The posterior cavity is more gradually contracted than the anterior; in the latter the excavation is, in most of the vertebræ, but slight (except beneath the floor of the neural arch), until it falls rather abruptly into the axial perforation. In an (?) anterior dorsal it is as widely excavated at the border as the posterior funnel. Another peculiarity s the abscence of the processes of the centrum; and a small capitular articulation is seen sessile on the border of the cup of two of the dorsals.

"The axis has a singular form, owing to the tubular perforation which continues the posterior excavation to the anterior face of the centrum. There are three articular faces, a larger subround inferior and two smaller superior, which border the neural canal in front and below and are separated from each other and the inferior face by the perforation in question. The anterior face slopes obliquely backwards and downwards, and is convex in transverse section. There is no facet for the free hypapophysis of the odontoid, but it appears that the inferior articular face was applied exclusively to the centrum of the atlas, as in *Sphenodon*. But the axis differs from that of the

latter genus in the abscence of a coössified odontoid process. Either that element is entirely wanting or it consists of two pieces, interrupted in the middle by the notochordal foramen, and in correspondence with superior articular facets. There is no true hypapophysis of the axis, and the only indication of lateral processes is a small articular facet on each side on the lower part of the rim of the posterior funnel. These may have been related to rudimental cervical ribs. The neural arch is broken off.

The dorsal vertebræ have their sides somewhat contracted; in one specimen the inferior face is rounded, in another, which I suppose to belong to a different part of the column, it is longitudinally acute. In this and another dorsal, where the parts are exposed, the floor of the neural canal is interrupted by a deep fissure, which has a triangular shape with apex downward when seen in profile. This is due to the fact that the opposite halves of the centrum are united by the circumferences of the articular cups, which have in profile an X shape. The diapophysis does not project far beyond the base of the neural arch and is compressed. The caudals are elongate, and resemble, in the forms of the centrum and neural arch, those of *Lælaps*. The neural spines are not preserved, but if present were directed well backwards, bearing the posterior zygapophyses, since the arch stands only on the anterior three-fifths of the centrum. Chevron facets are not distinct, but two emarginations on the rim of the posterior face of one of the vertebræ indicate their existence. In other centra even these notches are wanting. The tail was evidently tapering. There is no evidence of the transverse fissures seen in *Sphenodon* and many *Lacertilia*, nor are there any diapophyses on the caudal vertebræ preserved.

Specific characters: "There is a shallow fossa in the entering angle between the superior and inferior articular facets of the front of the axis, and the centrum of the same is obtusely keeled below. The border of the anterior face of the dorsal vertebræ with keeled centrum is undulate. The obtuse inferior face of another dorsal is rugulose, and the edge of the face is not undulate. The inferior faces of the two caudals are marked with fine parallel grooves, while in another caudal and the (?) sacrals the same is smooth. There are some longitudinal ridges on the upper side of the larger caudal."

MEASUREMENTS.

"Length of centrum of axis	.006^{m}
Width do. at middle behind	.008
Depth do. (oblique)	.010
Length centrum of sharp keeled dorsal	.014
Depth do. behind	.012
Width do. behind	.012
Length centrum rounded dorsal	.012
Depth do. behind	.011
Width do. behind	.010
Width neural canal do.	.004

Length centrum larger caudal - - - -	.014^m
Width do. - - - - - - - -	.008
Depth do. - - - - - - - - -	.008
Length smaller caudal - - - - - -	.010
Depth centrum do. - - - - - - -	.007
Width do. - - - - - - - -	.007 "

[Nos. 6530 (type specimen), 6531, and 6578.]

Clepsydrops pedunculatus Cope. Plate II, Figs. 4*a*, 4*b*, 4*c*, 4*d*; Figs. 5*a*, 5*b*, 5*c*, 5*d*.

Clepsydrops pedunculatus Cope, 1877, Proc. Am. Phil. Soc., p. 63.

This genus was established on two vertebræ, a third cervical, and an anterior caudal, regarded by Cope as a dorsal.

"Both differ from corresponding vertebræ of *C. colletti* and *C. lateralis* (this is evidently a slip on the part of the describer; there is no *C. lateralis; C. vinslovii* is evidently referred to, as it was the only other species of the genus described at this date) in having elongate diapophyses for the attachment of the ribs. These are present in the other species, but are either very short, or sessile. The third cervical has a broad reverted anterior lip-like margin of the anterior articular face, which resembles the corresponding part in *C. lateralis* (*vinslovii*) in not being produced below. The median line is keeled, and there is a shallow longitudinal groove on the upper part of the sides. The posterior articular face is regularly funnel shaped. The diapophyses are very stout, and are directed a little downwards and strongly backwards. The articular faces are single, look downwards and outwards, and are wide above, and narrow below. The base of the neural canal is deeply incised, as in the other species."

MEASUREMENTS.

" Diameter of centrum	antero-posterior - - -	.015 ^{m}
	transverse - - - -	.0125
	vertical - - - - -	.012
Length of diapophysis above - - - - -		.009
Diameter of diapophysis	vertical - - -	.008
	antero-posterior -	.005 "

In the description of the supposed dorsal attention is called to the long and slender diapophysis; it is evident that this is not a diapophysis, but an anchylosed rib with the distal broken portion inclined forward, as is characteristic of the anterior caudal ribs of the *Rhyncocephalia*. Speaking of other portions of the vertebra, the describer says: "There is no recurved rim of the articular extremities, but the surface does not pass regularly into the foramen chordæ dorsalis, but by an abrupt descent at its mouth. The

sides of the centrum are concave, and the inferior portion forms a prominent rounded rib."

MEASUREMENTS.

" Diameter of centrum	antero-posterior	.016^{m}
	transverse	.015
	vertical	.016 "

[Nos. 6534 (type specimen) and 6535.]

Clepsydrops vinslovii Cope. Plate II, Figs. *7a, 7b, 7c, 7d.*
Clepsydrops vinslovii Cope, 1877, Proc. Am. Phil. Soc., p. 62.

This species was based on a single cervical vertebra with which others were uncertainly identified. The specific characters given are as follows: " The inferior median line is a keel; some distance above it, the sides of the centrum are full, rising in a longitudinal angle. There is no constriction or fossa below the diapophysis as in *C. colletti.* The latter is anterior in position, is vertically compressed, and is curved forward for a short distance below. The posterior articular face is regularly funnel-shaped from the margin; the anterior face has a broad recurved lip. This passes around the inferior margin, which is not projected forwards as in *C. colletti.* The zygapophyses are well developed, and stand close together. The neural spine is compressed, and the basal portion points somewhat forwards."

MEASUREMENTS.

" Length of centrum		.011^{m}
Diameter of posterior articular face	vertical	.009
	transverse	.009
Vertical diameter of diapophysis		.006
Expanse of posterior zygapophysis		.009
Antero-posterior diameter of base of neural spine		.005
Transverse diameter of neural arch		.006 "

[Nos. 6532 (type specimen) and 6533.]

Lysorophus tricarinatus Cope. Plate II, Figs. 12*a*, 12*b*, 12*c*.
Lysorophus tricarinatus Cope, 1877, Proc. Am. Phil. Soc., p. 187. (Pal. Bull., No. 26.)

The type specimens consist of two vertebræ and a portion of a third. The generic characters given by Cope are as follows: "Vertebræ amphicœlian, perforated by the foramen chordæ dorsalis. Neural arch freely articulated to the centrum. Floor of neural canal deeply excavated. No processes or costal articulations on the centrum, which is excavated by longitudinal fossæ. Centrum not shortened." Specific characters: "Two centra and a portion of a third represent this species. The former are a little longer than wide and a little depressed. The facet for the neural arch is an elongate plane truncating the border of the fossa of the neural canal on each side,

for one half to three fifths the length of the centrum. Two deep longitudinal fossæ extend on each side of a median rib of the inferior face; and they are separated above by a narrower rib from another longitudinal fossa which is below the base of the neural arch.

MEASUREMENTS.

" Diameter of centrum	longitudinal - - -	.0055^{m}
	vertical - - -	.0038
	transverse - - -	.0040
Length of facet for neurapophysis - - -		.0035
Width of neural canal - - - - -		.0020 "

This form differs very decidedly from any other in the collection in the prominence of the keel and the lateral ridges; they, or rather the fossæ between them, are developed to an extent that almost destroys the centrum, leaving but a very slender tube surrounding the notochord. A few centra of larger size show strongly developed keels and free neural arches, but much stouter proportions.

[Nos. 6526 (the type specimen; it is badly broken), 6527, and 6528.]

Archæobelus vellicatus Cope. Plate III, Fig. 1.

"*Species No. 4*" Cope, 1877, Proc. Am. Phil. Soc., p. 56.

Archæobelus vellicatus Cope, 1877, Proc. Am. Phil. Soc., p. 192. (Pal. Bull., No. 26.)

This genus is represented by teeth alone. In his discussion of the form Cope says, in the earlier paper, "there is nothing to prevent their (the teeth) reference to the *Lacertilia*." The generic description is as follows: "The form is conical, and the surface is not grooved nor furnished with prominent ridges. The interior is hollow, and the walls are composed of a few concentric layers without external enamel or cementum. The solid base to which it is attached is shallow, presenting smooth surface on the opposite side, which is deeply impressed by a longitudinal groove at one end." The specific description is given in the earlier paper: "The crown is conic, subround in section, and curved backward. There are no cutting edges, and the base is a little flattened in front and behind. On each of the faces thus formed, there is an open, shallow groove, sometimes obsolete. There are no other grooves or sculpture on the teeth. . . . . One of the specimens displays an extensive pulp cavity."

MEASUREMENTS.

	First specimen	First specimen	Second specimen
" Diameter of base -	.004^{m} long	.008^{m} short	.005^{m}
		First specimen	Second specimen
Length of crown - - -		.010^{m}	.015^{m} "

There are several specimens of the isolated teeth described by Cope in the collection, but in addition a considerable portion of a maxillary bone which

shows many points of interest. In all the single teeth, as described by Cope, they are attached to a portion of the jaw and unaccompanied by any other teeth, but there is posterior to the tooth a cavity which, as shown by the more perfect jaw, accommodated a second tooth larger even than the first. In the fragment of the jaw there are, first, three quite small teeth, and then, supported by a swollen portion of the rim, there are two very large canine teeth ; posterior to these, three teeth about equal in size to those anterior to the canines, and then five smaller ones. As both ends of the piece are incomplete, it is certain that there were more teeth than here recorded. Several differences from *Clepsydrops* and *Dimetrodon* are apparent : first, the anchylosis of the teeth to the jaw, instead of being inserted in well defined alveoli ; second, the presence of two enlarged canines instead of one, and third, the possible absence of the diastema anterior to the canines ; for in the *Dimetrodon* the anterior teeth of the maxillary decrease to small size immediately and the notch of the diastema begins just anterior to the canine and below the external nares, but here, though the anterior tooth is almost below the nares, there is no sign of the beginning of the notch, if any existed. The teeth are all more or less rounded in section and show no sign of a cutting edge. In general appearance the jaw is much like that of the Pelycosaurians ; *i. e.*, with a thin outer wall and a heavy shelf-like dentigerous edge.

Associated with the fragments of the upper jaws are several portions of the lower jaws showing the symphasial region. Some of the anterior teeth, about the third and fourth, seem to have been slightly larger than the others, but as such a small part is preserved it is impossible to say definitely. These fragments may have belonged to the genus *Clepsydrops*, and, indeed, the fragments of the upper jaws also.

[Nos. 6524 and 6525.]

UNNAMED SPECIMENS.

Besides the specimens named and described by Cope there are present in the collection many isolated bones from different parts of the skeleton which cannot be identified with certainty as belonging to any of the forms described ; that they belong to some of them is practically certain. The fact that the bones are nearly always found isolated and generally in a fragmentary condition prevents any attempt at a restoration of the skeleton, but their resemblance to corresponding bones from the Texas deposits makes it probable that the animals from the two regions did not differ materially in form. One fact is noticeable, the

absence of animals of any great size as compared with the Texas forms.

Skull.—The skull is represented by two nearly perfect maxillaries, apparently the bones from the two sides of the same specimen, and several fragments showing the occipital condyles.

The premaxillaries are similar to those of *Dimetrodon* and of *Empedias* as figured by Cope. The external surface is pitted, and there was evidently a large opening of the external nares. The teeth do not show any great disparity in size nor are they chisel-shaped; there is no evidence of the presence of a diastema as in the *Pelycosauria* in general, but this may be due to the imperfection of the bone. Plate III, Figs. 2, *a* and *b*. [No. 6536.]

The occipital condyles are well rounded, hemispherical in outline, the upper edge being slightly concave, and marked by a pit near the upper edge. [No. 6537.]

Vertebræ.—There are a great many vertebræ, either isolated specimens or small lots belonging together; the majority evidently belong to one or the other of the three species of *Clepsydrops* described. There are two lots that seem different from the others.

Two vertebræ very much larger than the others apparently belong to the lumbar or posterior dorsal region. They are characterized by the breadth of the centrum as compared by its height. The lower surface is marked by a rounded but prominent keel. One shows measurements corresponding very closely with those given by Cope for *C. natalis* from Texas. It is very possible that they represent this species. [No. 6538.]

A second set of vertebræ resemble in large measure those of *Lysorhophus tricarinatus* in the free articulation of the neural arch to the centrum and the general form of the centrum; they differ, however, in the absence of the strongly marked keels and the deeply incised fossæ between them. They vary greatly in size, some being as large as those of *L. tricarinatus* and others three or four times as large. If it were not for the presence of vertebræ of different size they might be regarded as dorsals of the described species. As it is, they seem to indicate a possible new species.

MEASUREMENTS.

"Length of a centrum	$.011^{m}$
Breadth of a centrum	.011
Length of a second centrum	.007
Breadth of a second centrum	.006 "

Plate II, Fig. 13, *a*, *b*, and *c*. [No. 6529.]

Scapula.—There are many incomplete scapulæ in the collection. They are all of small size, but resemble in form those figured by Cope (Proc. Am.

Phil. Soc., Aug. 1884, and Proc. Am. Assoc. and Sc., 1884, Vol. XXXIII), and Case (Trans. Am. Phil. Soc., 1899, Vol. XX.) One specimen shows the proximal end with articular cavity for the humerus formed by the scapula and coracoid. The scapula is perforated by a foramen just above the articular face. Plate III, Fig. 3. [No. 6540.]

Humeri.—There are four types of humerus. One, the largest, is relatively much shorter and stouter than the others, and is remarkable for the strong articular faces and the generally robust character. The proximal end is marked by prominent rugosities and the deltoid crest is laterally expanded, much more so than in the other forms, and very rough. Length .14^m; width of the head at the deltoid ridge .057^m. Plate III, Fig. 4, *a*, *b*. [No. 6541.

The second form has a much longer shaft than the first, and at all points shows a greater elegance of form at the expense of strength, but the extremities are as well formed and the articulate surfaces as distinct. This probably belongs to one of the described forms of *Clepsydrops* from Illinois, probably the largest, *C. pedunculatus*. A smaller form of the same type is represented by the distal end of another humerus, which is perfectly preserved. The entepicondylar foramen is large and elongate, the ectepicondylar foramen is represented by a notch, as in all the *Pelycosauria;* the head for the proximal end of the radius is prominent, almost hemispherical and well formed, it is continuous with the articular surface for the ulna. Height of fragment .066^m, width at deltoid ridge .030^m. Plate III, Fig. 5, *a*, *b*, *c*, and Fig. 6. [Nos. 6542, 6543, and 6575.]

The third type is represented by the distal end of a very small form similar in many respects to the foregoing, but with the internal process rounded and truncated and the entepicondylar foramen missing. The form is very small and the shaft of the bone was slender, but the distal extremity shows a strong development. The process forming the ectepicondylar notch is prominent, and the portion of the distal extremity on either side of the articular surface extended below the surface instead of lying in a line with it or not reaching so far. This form may be the same as the "No. 6" mentioned by Cope in his first contribution to the fauna of the Texas Permian, but as it was not described nor figured, it is impossible to say definitely. The humerus "No. 6" is regared by Cope as belonging to a possibly fossorial animal, this may be true of the present form, but there is no vertabræ in the collection which could go with such a type. Plate III, Fig. 7. [No. 6544.]

The fourth and last type differs very considerably from the others. The ends are concave, as if they had been cartilaginous in life, and there are no articular surfaces distinguished. The extremities are at right angles to each other, and there is a small deltoid process, continuous with the proximal end. The entepicondylar foramen is present, but there is no trace of an

ectepicondylar notch. Length .038^{m}, width proximal end .0105^{m}, distal end .0205^{m}. Plate III, Fig. 8, *a, b, c, d.* [No. 6545.]

Ulnæ.—There are two types of ulna distinguished by the size only. One is nearly as large as the ulna of *Dimetrodon incisivus* and quite similar to it; the proximal end only is preserved; the other is smaller, represented by the proximal end also, and probably belongs to one of the smaller species of *Clepsydrops*. Plate III, Fig. 9. [Nos. 6546 and 6547.]

Femoræ.—The femora are mostly of the same type, but show considerable variation in size. They all have the distal articular surfaces upon the inner or lower face of the distal end, showing that the leg was habitually flexed and the animal progressed, probably, with the belly on or near the ground, in the manner of the alligator. One of the medium sized forms is figured (No. 6548). Length of one specimen, .077^{m}; a larger specimen, .107^{m}. Plate IV, Fig. 1, *a* and *b.* [Nos. 6548, 6549, 6550, 6551, 6552, and 6553.]

The distal ends of two very small femora are present; they lack well-developed articular surfaces, though the contour of the extremity is the same as in the larger specimens. It seems probable that they are immature forms. [No. 6552.]

Tibia.—There is one complete tibia, somewhat crushed, and the proximal end of another. The whole bone is larger at the proximal than at the distal extremity, and is considerably curved. The shaft is more or less flattened. The proximal end has two faces, which are distinct, or nearly so; they are oblong and lie with their long axes nearly at right angles to each other. The anterior extremity of one anticular face forms the upper portion of the cnemial crest. Measurements: length, .049^{m}. Plate IV, Fig. 2, *a* and *b.* [No. 6555.]

Fibula.—What appears to be a fibula is .053^{m} long. It is a slender bone, expanded at the extremities and quite strongly curved. Plate IV, Fig. 3. [No. 6554.]

Ilia.—There are two types of ilia of about the same size. Each presents two articular faces at the distal portion for articulation with the ischium and pubis and a rather deeper articular portion of the acetabulum; at the upper portion of the acetabulum there is a prominent overhanging process. The two forms differ principally in the anterior process of the ilium with which it is attached to the sacral vertebræ. In one form it extends almost straight forward (No. 6556) and in the other (No. 6557) it is curved and the anterior end is somewhat lower than the posterior. The inner side of each presents strong longitudinal ridges and there does not seem to be any articular facet for the vertebræ. In an incomplete fragment, in which the ischium and ilium are in contact, the acetabulum is seen to be quite deep. Plate IV, Figs. 4 and 5. [Nos. 6556, 6557, and 6558.]

Footbones.—There is a large series of footbones, the position of most of which it is impossible to determine. They are all well formed, with good articular surfaces, showing that the carpus and tarsus was fairly strong and well knit. Some of the more common bones of indefinite position are shown in Plate V, Figs. 18, *a* and *b;* 19, *a* and *b;* 20, *a* and *b.* [No. 6559.]

Astragali.—There seem to be two forms of astragalus. The first is much the more slender and smaller. There are two distinct facets for articulation with the calcaneum; the upper of these is the largest and is separated from the lower by a notch which, in combination with a similar notch separating the two articular faces on the calcaneum, forms a foramen between the bones. On the opposite side of the bone there is a large face set at an angle with the body of the bone, apparently for the tibia. The lower rim of the bone between the described regions has a narrow face for the bones of the tarsus. This ilium was ascribed by Cope to *clepsydrops colletii.* The form of the bone is shown in Plate IV, Fig. 7, *a, b, c, d.* [No. 6560.]

The second type is of stouter proportions than the first and larger; the articular faces are arranged much the same, but are broader and the face for the distal end of the tibia is more sharply divided into faces meeting at a considerable angle. Plate IV, Fig. 8, *a* and *b.* [No. 6561.]

Neither of these forms corresponds with the figure of the astragalus of *Clepsydrops leptocephalus,* published by Cope (Proc. Am. Phil. Soc., Aug. 1884; Am. Assoc. Ad. Sc. Vol. XXXIII, 1884), nor to an astragalus of *Pariotichus incisivus* in the collection of the Walker Museum.

The strong angulation of the tibial face is described by Cope as belonging to the genus *Dimetrodon,* so that it is possible that the larger astragalus in the Illinois material may represent that genus.

Calcanea.—The calcanea are of the type characteristic of most of the Permian reptiles from America. Large, subround disks of no great thickness; the side toward the astragalus presents two facets separated by a notch; above and below are facets for the fibula (?) and the tarsal bones. Plate IV, Fig. 9, *a* and *b.* [No. 6562.]

Metacarpals and Tarsals.—The metacarpals and tarsals are long and slender, with well developed articular faces. Plate V, Figs. 1 and 2. [No. 6563.]

Phalanges.—The phalanges show the same well developed form as the preceding row, even to the terminal series. The terminal series are slender, pointed, and curved, and evidently supported strong claws. Plate V, Figs. 3–9, and 10, *a* and *b.* [Nos. 6564 and 6565.]

Among the specimens that cannot be referred with certainty to any form are the following:

Teeth.—There are several isolated teeth or portions of jaws with teeth attached, which cannot be assigned to any of the described forms. It is probable that if more complete material were at hand they would be found to belong to forms already described, either from Illinois or Texas.

"*Species one*" Cope, 1877, Proc. Am. Phil. Soc., p. 56.

This is an incomplete maxillary with six broken teeth. "They stand in close juxtaposition and are of equal size. The basal half or more of the crown displays the character of deep inflections or grooves. These teeth belong to some sauroid fish or batrachian." Plate V, Fig. 12. [No. 6566.]

"*Species two*" Cope, 1877, Proc. Am. Phil. Soc., p. 56.

A fragment of a mandibular ramus with four teeth. "The anterior of these is larger and is separated from the others by an edentulous space. Their crowns are rather elongate and are compressed, having cutting edges fore and aft. Both edges contract to the apex, but the anterior the more so. There are a few shallow grooves at the base, but they appear to be superficial only." As remarked by Cope, it is impossible to tell whether they belong to an amphibian or a reptile. Plate V, Fig. 11. [No. 6567.]

"*Species three*" Cope, 1877, Proc. Am. Phil. Soc., p. 56.

"Two stout, slightly flattened, conic teeth, without cutting edges, represent this species. They are anchylosed to a very thin plate of bone, a part of which adheres to each. The base is oblique, expanding more in one direction than in another. The greater part of the crown is marked by closely placed parallel grooves, which are more numerous than in the species No. 1. They are larger than those of No. 2, measuring .004^{m} in diameter at the base. They may belong to any one of a number of known genera of batrachia or sauroid fishes." [No. 6568.]

Besides these, there are two teeth that seem to indicate forms not otherwise represented in the collection. The first is rather conical and recurved, the upper end truncate, but the inner side shows a concave region of wear against the opposed tooth. This would seem to show that it is either an incisor or one of the lateral teeth, probably the first, of some member of the *Diadectidæ*. Plate V, Fig. 23, *a* and *b*. [No. 6569.]

The second is a very stout, conical tooth, much larger than any other in the collection. Its surface is marked with deep, irregularly arranged grooves. Plate V, Fig. 24. [No. 6570.]

A lower jaw, nearly complete, resembles very closely that of *Pariotichus* from Texas. The articular region is complete and shows a well formed face and a prominent spur extending posterior to the cotylus. Fragments of other jaws show the same feature. The outer side is marked by strong reticulate sculpture, which at the posterior part seems to radiate from a point on

the lower margin about an inch from the posterior end; on the anterior portions the lines are straighter and lie parallel to the length of the jaw. The teeth were very small. A small fragment attached to the inner side of it is covered with many minute teeth; this may be a portion of the dentition of the upper jaw. [No. 6571.]

A collection of fragments showing a fine sculpture on one side are probably portions of the skull of *Diplocaulus*. Among these are imperfect plates with a much coarser sculpture, which are probably abdominal scales. [No. 6572.]

There are two pubes nearly complete; they may belong to *Cricotus*. There is a considerable portion of the acetabular face present. This portion of the bone is thickened, and besides supporting the acetabular face has a broad face for the ilium. Just below these faces the bone is perforated by a foramen. Beneath the foramen is the symphasial region, which is remarkably broad and thick in proportion to the rest of the bone. In general the outline of the bone was subround, but the lower posterior portion was very thin, and portions have been broken away in both specimens. On the upper margin, posterior to the facet for the ilium, there is a slender tubercle which bears an articular facet; in one specimen this is isolated and in the other it is confluent with a broad facet on the thickened posterior border. Plate IV. Figs. 6, *a* and *b*. [No. 6573.]

There are a few coprolites of small size. They show spiral markings indicative of a spiral vale in the stomach of the form to which they belonged. [No. 6574.]

EXPLANATION OF PLATES.

PLATE I.

FIG. 1. *Janassa linguæformis*. Twice nat size. *a*) from below, *b*) from above, *c*) from the side.

FIG. 2. *Janassa gurleyna*. Twice nat. size. *a*) from below, *b*) from above, *c*) from the side.

FIG. 3. *Pleuracanthus quadraseriatus*. *a*) from the side, *b*) from the front.

FIG. 4. *P. gracilis*.

FIG. 5. *P. compressus*. *a*, *b*, *c*, and *d*.

FIG. 6. *Sagenodus vinslovii*. *a*) from below, *b*) from above.

FIG. 7. *S. vabasensis*.

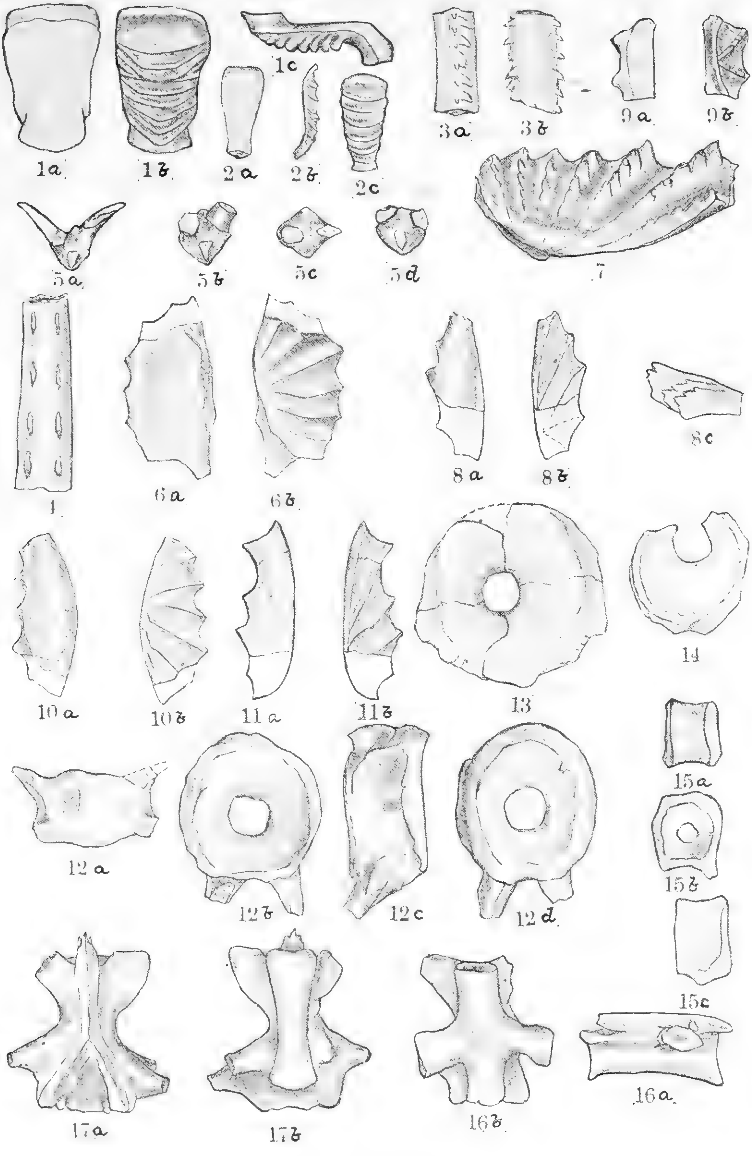
FIG. 8. *S. gurleyanus*. *a*) from below, *b*) from above, *c*) from the side.

FIG. 9. *S. pusillus*. *a*) from below, *b*) from above.

FIG. 10. *S. fossatus*. *a*) from below, *b*) from above.

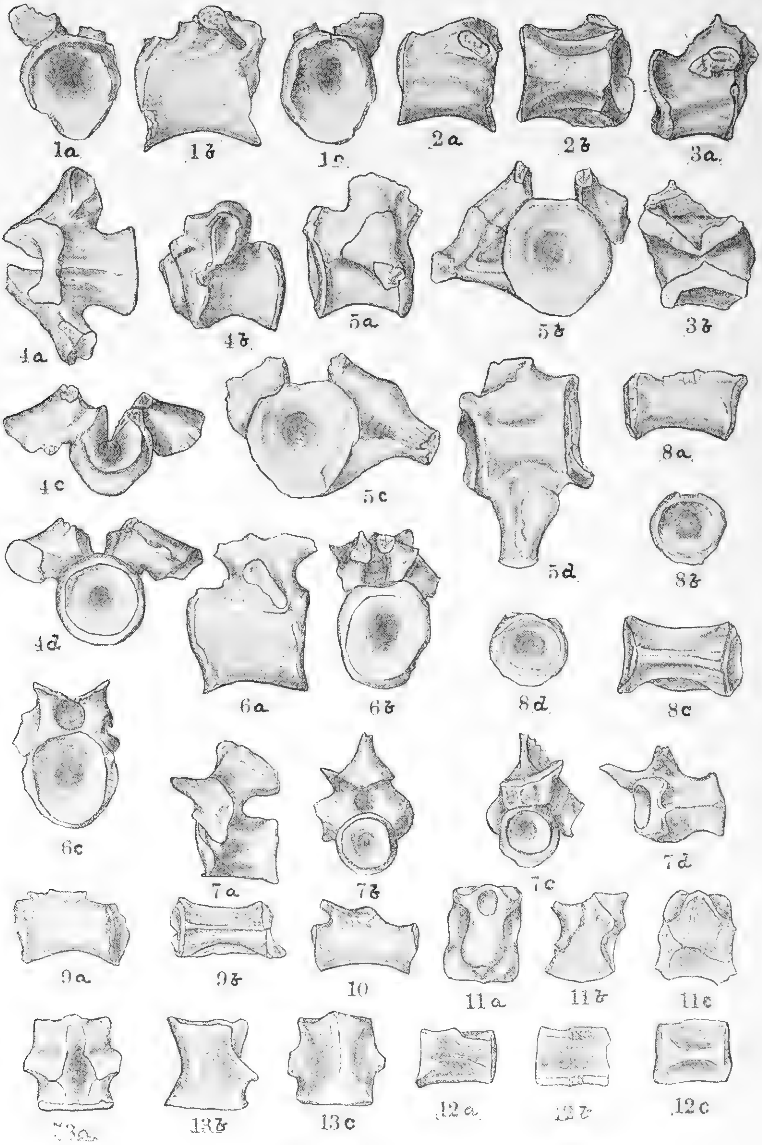
FIG. 11. *S. paucicristatus*. *a*) from below, *b*) from above.

JOUR. GEOL., Vol. VIII, No. 8 Plate I



Permian vertebrates.

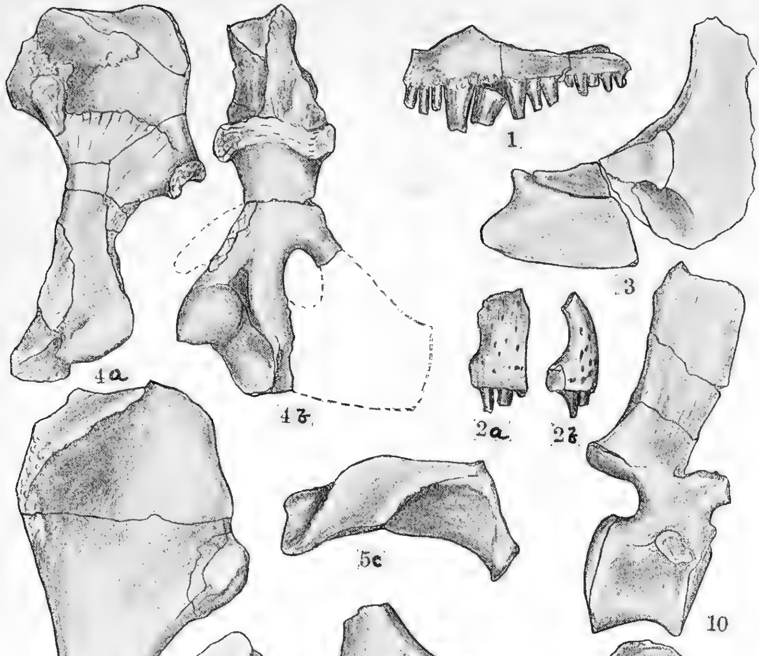
JOUR. GEOL., Vol. VIII, No. 8 Plate II



Permian vertebrates.

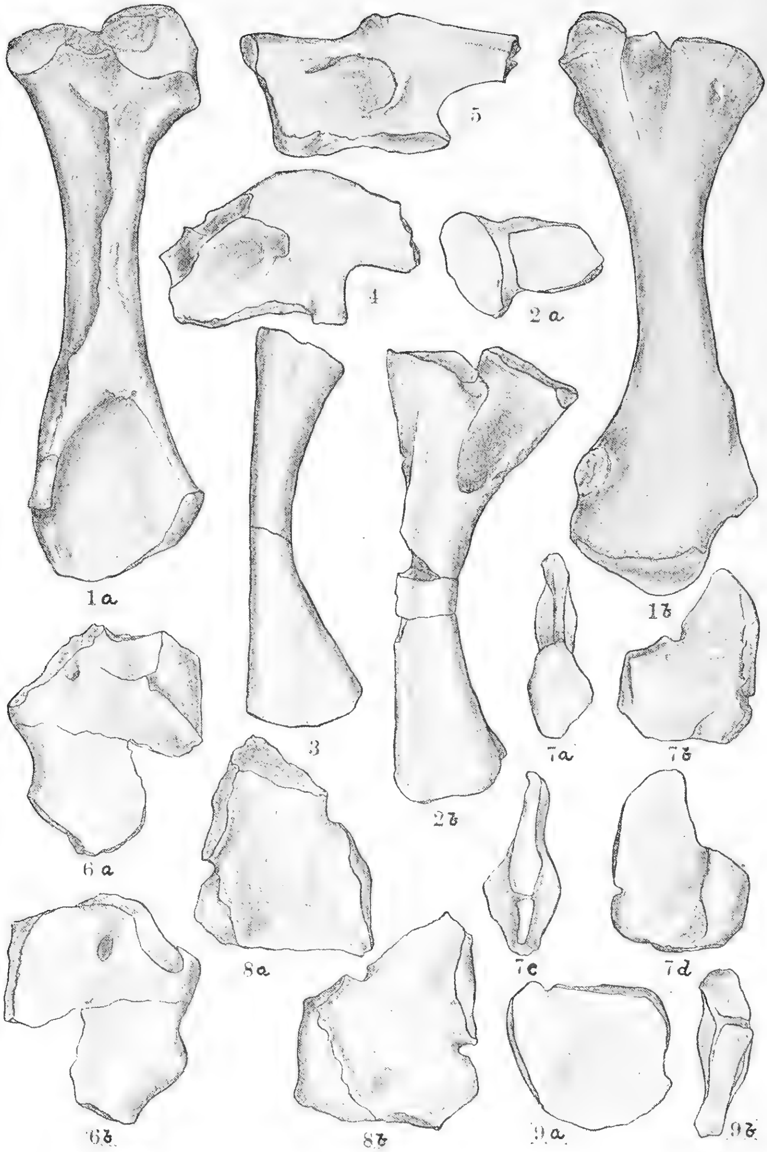
Jour. Geol., Vol. VIII, No. 8

Plate III



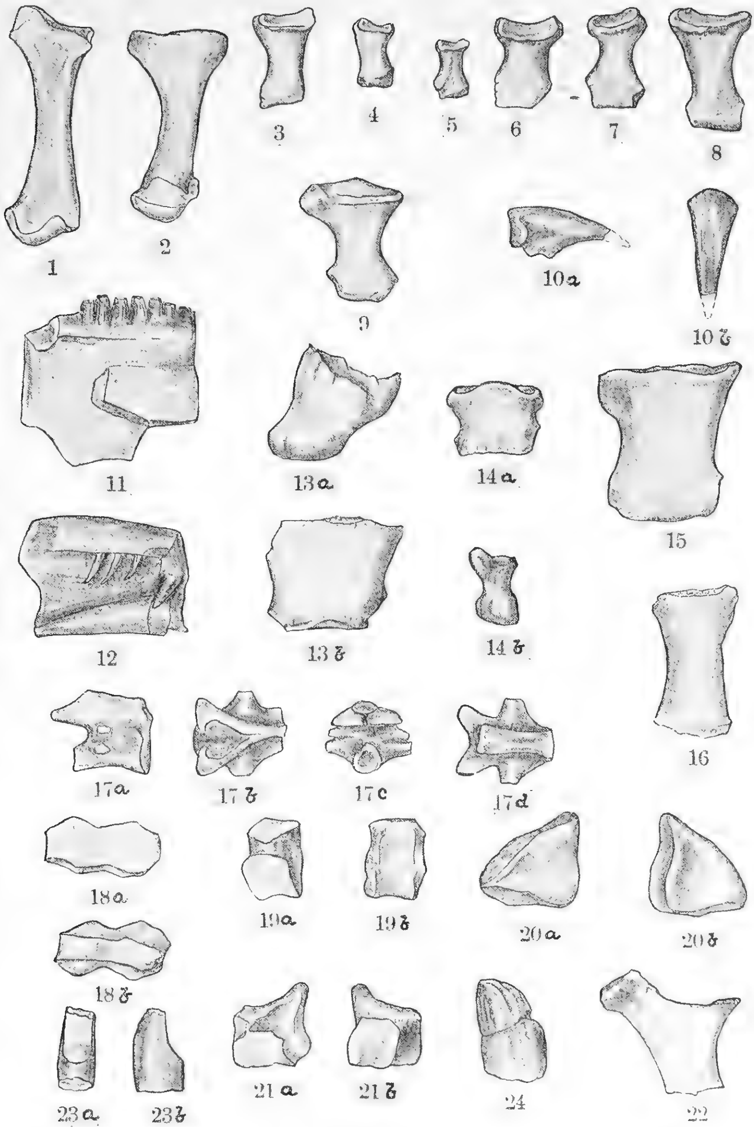
Permian vertebrates.

Jour. Geol., Vol. VIII, No. 8 Plate IV



Permian vertebrates.

Jour. Geol., Vol. VIII, No. 8 Plate V



Permian vertebrates.

FIG. 12. *Cricotus heteroclitus.* Intercentrum. *a*) from above, *b*) from before, *c*) from the side, *d*) from below.

FIG. 13. *C. heteroclitus.* Intercentrum.

FIG. 14. *C. heteroclitus.* Intercentrum.

FIG. 15. *C. gibsonii.* Intercentrum.

FIG. 16. *Diplocaulus salamandroides* Dorsal vertebra. *a*) from the side, *b*) from below. Twice nat. size.

FIG. 17. *D. salamandroides.* Dorsal vertebra. *a*) from above, *b*) from below. Twice nat. size.

PLATE II.

FIG. 1. *Clepsydrops colletii.* Dorsal vertebra. *a*) anterior, *b*) lateral, *c*) posterior.

FIG. 2. *C. colletii.* Dorsal vertebra. *a*) lateral, *b*) inferior.

FIG. 3. *C. colletii.* Dorsal vertebra. *a*) lateral, *b*) showing vertebra divided on median line.

FIG. 4. (?) *C. colletii.* *a*) inferior, *b*) lateral, *c*) anterior, *d*) posterior.

FIG. 5. *C. pedunculatus.* Anterior caudal. *a*) lateral, *b*) anterior, *c*) posterior, *d*) inferior.

FIG. 6. *C. sp.* Dorsal vertebra. *a*) lateral, *b*) posterior, *c*) anterior.

FIG. 7. *C. vinslovii.* Dorsal vertebræ. *a*) lateral, *b*) posterior, *c*) anterior, *d*) inferior.

FIG. 8. *C. sp.* Caudal vertebra. *a*) lateral, *b*) anterior, *c*) inferior, *d*) posterior.

FIG. 9. *C. sp.* Caudal vertebra. *a*) lateral, *b*) inferior.

FIG. 10. *C. sp.* Caudal verebra, lateral.

FIG. 11. *C. sp.* Axis. *a*) anterior, *b*) lateral, *c*) inferior.

FIG. 12. *Lysorhophus tricarinatus.* Dorsal (?) vertebræ. *a*) from the side, *b*) from above, *c*) from below.

FIG. 13. *L. sp.* Dorsal (?) vertebræ. *a*) from above, *b*) from the side, *c*) from below.

PLATE III.

FIG. 1. *Archeobolus vellicatus.* Maxillary.

FIG. 2. Premaxillary. *a*) from before, *b*) from the side.

FIG. 3. Scapula and Coracoid.

FIG. 4. Humerus. × ½. *a*) lateral view, *b*) posterior view.

FIG. 5. Humerus. *a*) anterior, *b*) proximal end, *c*) lateral, half nat. size.

FIG. 6. Humerus. Distal end of same form as 5.

FIG. 7. Humerus. Distal end.

FIG. 8. Humerus. *a*) anterior view, *b*) lateral, *c*) and *d*) outlines of the proximal and distal faces in natural position.

FIG. 9. Proximal end of Ulna.

PLATE IV.

FIG. 1. Femur. *a*) anterior, *b*) posterior.

FIG. 2. Tibia. *a*) proximal end, *b*) anterior view.

FIG. 3. Fibula.

FIG. 4. Ilium.

FIG. 5. Another type of ilium.

FIG. 6. Pubis. *a*) inner view, *b*) outer view.

FIG. 7. Astragalus of *Clepsydrops sp.* *a*) tibial face, *b*) anterior (?) face, *c*) calcaneal face, *d*) posterior (?) face.

FIG. 8. Astragalus of *Clepsydrops sp.* *a*) anterior (?) face, *b*) posterior (?) face.

FIG. 9. Calcaneum. *b*) astragalus face.

PLATE V.

FIGS. 1 and 2. Metacarpals of *Clepsydrops.*

FIGS. 3–9. Phalanges of *Clepsydrops.*

FIG. 10. Terminal phalanx of *C.* *a*) lateral, *b*) superior views.

FIG. 11. "Species one."

FIG. 12. "Species two."

FIG. 13. Phalanges of *Cricotus.* *a*) lateral, *b*) anterior views.

FIG. 14. Phalanges of *Cricotus.* *a*) anterior, *b*) lateral views.

FIGS. 15 and 16. Phalanges of *Cricotus.*

FIG. 17. *Diplocaulus salamandroides.* Dorsal vertebra. *a*) lateral, *b*) superior, *c*) terminal, *d*) inferior views.

FIGS 18–21. Carpal bones.

FIG. 22. Proximal end of a rib

FIG. 23. Incisor tooth. *a*) anterior view, *b*) lateral.

FIG. 24. Tooth.

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SOME PRINCIPLES CONTROLLING THE DEPOSITION OF ORES.[1]

I WOULD hardly have ventured to talk on the subject of ore deposits to you if I had not approached the subject from a different point of view from the majority of men who have considered it. The point of view from which the subject of ore deposits has been most frequently considered has been that of a study of ore deposits themselves. A geologist or mining engineer has studied this or that ore deposit, or a number of ore deposits in different districts, and has then generalized concerning the ore deposits of other districts, and perhaps of the world. I also have considered the subject of ore deposits to some extent from that point of view, but if I had done this only, I would not have ventured to give a general address upon the subject.

Some years ago I took up the question of the alterations of rocks — the alterations of all rocks by all processes. In treating this subject it became necessary for me to consider somewhat fully underground water; the principles which control its flow; the manner in which it works; the results which it accomplishes. After I had reached certain conclusions upon that subject it seemed to me that the deposition of most ores was a special case falling under the general principles controlling the work of underground water. Therefore it is from the point of view of the circulation and work of underground water that I wish to consider the subject of ore deposits tonight. However, I cannot go into the subject fully, and will be obliged to ask those of you who are especially interested in it to refer to my more

[1] An address presented to the Western Society of Engineers at Chicago, June 13, 1900. The address is also printed in the journal of that society for December 1900.

This paper covers the same ground as a paper on the same subject, in a somewhat different form, which has already been published in the Transactions of the American Institute of Mining Engineers. Vol. XXX, 1900, pp. 1–151.

extended paper found in Vol. XXX of the *Transactions of the American Institute of Mining Engineers.*

There are three great classes of ore deposits; (1) those which are produced by igneous processes; (2) those which are produced by the direct processes of sedimentation; (3) those which are produced by the work of underground water. The last class is by far the largest, and it is the only one which I shall consider this evening.

My first, then, and my fundamental premise is, *That the most important class of ore deposits is the result of the work of underground water.* This premise I shall not attempt to prove; but because it is accepted by most geologists and by most mining engineers shall use it as a starting point.

My second fundamental premise is, *Ore deposits are derived from the outer crust of the earth, from that part of the crust of the earth which I have called the zone of fracture.*[1] There has been much discussion as to whether ore deposits are produced by descending waters, lateral-moving waters, or ascending waters. One of the most comprehensive papers which has been presented upon this subject was by Posepny.[2] In this paper Posepny holds that the original source of the metals of practically all the ore deposits of the class produced by underground water is the Barysphere (heavy-sphere), and therefore that the metals come from very far below the surface of the earth. The water in some mysterious way came from this heavy sphere, presumably very deep seated. The water rising from the Barysphere, where the rocks are supposed by some to contain more metalliferous material than near the surface, brought the metals of the ore deposits to their present positions. This view has been presented at great length by Posepny, ably argued, and he has had many disciples. Now it seems to me that the well-established principles of physics absolutely disprove this

[1] Principles of North American pre-Cambrian Geology, by C. R. VAN HISE: Sixteenth Ann. Rept. U. S. Geol. Surv., 1894–5, Pt. I, p. 589.

[2] The Genesis of the Ore Deposits, by F. POSEPNY: Trans. Am. Inst. Min. Engineers, Vol. XXIII, 1894, pp. 197–369.

hypothesis; and it further seems to me that observed geological phenomena also disprove it.

I have elsewhere divided the outer crust of the earth into zones, in descending order as follows: a zone of fracture, a zone of combined fracture and flowage, and a zone of flowage.[1]

Now, we will suppose that the crushing strength of the strongest rock is such that at a depth of twenty thousand meters below the surface the weight of the superincumbent rock (less the floating effect of underground water) is as great as the crushing strength of the rock. We will suppose that such a rock as the Berlin granite of Wisconsin, the strongest rock yet tested, having a crushing strength of 47,674 pounds per square inch,[2] extends from the surface to an indefinite depth. We will further suppose that in some way openings of some kind, say large cracks, are produced at the depth where the rock is under weight as great as its crushing strength. What would happen? You engineers know very well the rock would be crushed and the openings would close. Therefore at a depth of more than 20,000 meters below the surface of the earth, where the weight of the superincumbent rock is greater than the strongest rocks, if it be supposed that cracks of a considerable size could be formed, the pressure would crush the rocks and close the cracks. But the crushing strength of the great majority of the strong rocks does not exceed one half that of the Berlin granite. Moreover rocks at considerable depth are at higher temperatures than normal, and this probably weakens them. Consequently upon physical grounds we are prohibited from supposing that there are cracks and crevices of considerable size at more than a very moderate distance below the surface of the earth. But this conclusion does not rest upon physical principles alone. I have shown that there is another way besides crushing by which

[1] Principles of North American pre-Cambrian Geology, by C. R. VAN HISE: Sixteenth Ann. Rept. U. S. Geol. Surv., 1894–5, Pt. I, p. 589.

[2] Building and Ornamental Stones of Wisconsin, by E. R. BUCKLEY: Bull. Wis. Geol. and Nat. Hist. Surv., No. 4, 1898, p. 390.

rocks are readjusted to deforming stresses.[1] If the movement be slow and the temperature that of moderate depth the stress does not need to accumulate so that it shall be greater than the crushing strength of the rocks. Under such conditions, long before the crushing strength is reached, the contained water begins to act upon the material of the rocks and re-arranges it by continuous solution and deposition; so that it behaves as a plastic body. At all times the rock is a solid except for the infinitesimal amount held in solution; and yet it continually adjusts itself to the deforming stresses. A great many rocks which have been thus deformed under deep-seated conditions have a laminar structure which is analogous, not exactly similar, but analogous, to the leaves of a book. To make the analogy exact it would be necessary to suppose that the leaves are welded together, *i. e.*, held firmly by the molecular attractions between them. What has happened in the case of these laminar rocks? They have been transformed from a massive to a laminated form by recrystallization, but in many cases combined with mineral granulation and differential movements of the mineral particles. During the process of recrystallization, for each mineral particle, material is continually taken into solution on the sides where subjected to greatest stress and deposited on the edges where the stress is less, until the laminar structure is produced. The process of adjustment largely and in many instances mainly by continual solution and redeposition is rock flowage. Now rocks in which this process has taken place are found at the surface at many places. Moreover these rocks are frequently those of great strength. In many places it is certain that the amount of material which has been removed by erosion since the rocks were recrystallized is not more than 2000 or at most 3000 meters. Since, therefore, the process of rock flowage often takes place at much less depth than that at which rocks are crushed, it follows that large openings are not likely to exist at depths so great as above calculated for the closing of openings

[1] Metamorphism of Rocks and Rock Flowage, by C. R. VAN HISE: Bull. Geol. Soc. Am., Vol. IX, pp. 269–328, Pl. XIX.

by crushing. It is highly probable that few openings of appreciable magnitude exist at depths so great as 10,000 meters.

Therefore from the principles of physics and from observation we conclude that crevices and cracks of considerable magnitude do not exist below a very moderate depth. I would not say that minute cavities filled with liquid do not exist in the zone of rock flowage; I would not say that very small openings filled with gases may not exist in that zone; but there is every reason to believe that such cavities are exceedingly small. And it is well known that ore deposits in order to be of economic value must be of considerable magnitude. Such deposits were not formed in the minute and discontinuous openings filled with gas or liquid which very possibly exist at great depth.

But let us now consider this subject from another point of view. You as engineers know very well that the friction of a moving liquid increases very rapidly as the size of the passage through which it moves decreases. This is true even of super-capillary tubes. It is still more true of capillary openings, and the resistance goes up very rapidly as the capillary tubes decrease in size. When the openings become so small that the molecular attractions extend from wall to wall or the openings are subcapillary, the resistance is so great that the flowage is practically nil.[1] Now it is perfectly evident that a deposit of mineral material in an opening is not the work simply of the water that occupied it at any one time. Ordinarily, underground solutions of silica do not contain upon the average more than one part of silica per 100,000 parts of water, so that if an opening be filled with quartz, the most abundant of all the gangue minerals, we must suppose at least 100,000 times as much water went through the opening as there was quartz deposited. Therefore it is perfectly clear that the material for large ore deposits can only be gathered and the ores deposited in the zone where there is a vigorous circulation, and vigorous circulation is

[1] Metamorphism of Rocks and Rock Flowage, by C. R. VAN HISE: Bull. Geol. Soc. Am., Vol. IX, p. 272.

impossible in the deep-seated zone in which there are no continuous cracks and crevices of considerable size; hence the hypothesis of the derivation of the metals of the ores from the Barysphere is untenable. Valuable ore bodies have been deposited in openings and passages of considerable size and by a vigorous underground circulation. Since the magnitude of openings and vigorous circulation are correlative with, and exist only in the upper zone, that of fracture, the ores must have been derived from and deposited in this upper part of the crust of the earth.

If, then, we admit the fundamental premise, that the majority of ore deposits are the work of underground water, it seems to me that the conclusion cannot be escaped that the metals which are in the ore deposits are immediately derived from an upper zone, probably having a maximum depth of 10,000 meters, or seven or eight miles, in which the circulating waters are vigorous and effective.

However, I do not assert that now, or at any time in the past, metals for ores have not been derived ultimately from a deeper source through the agency of vulcanism, the medium of transfer being the igneous rocks. We do not know how deep down the igneous rocks which are intruded into the zone of fracture or flow out at the surface of the earth are transformed to magma, if they have not always existed as magma. We do not know very well the process by which the igneous rocks make their way up through the solid rocks of the zone of flowage. We do know, however, that they come from a very considerable depth, and take advantage of openings and cracks and crevices as soon as they reach the zone of fracture. For instance, in the Sierra Nevada, where there are various great sets of joints in the granite—vertical, inclined, and horizontal—the lava coming up from below has wedged itself into these joints, producing sets of parallel dikes. As these joints are utilized by the igneous rocks, so are openings of other kinds where igneous rocks intrude the zone of fracture. Igneous rocks in vast quantities as lava are poured out on the surface or as tuff fall upon it.

These igneous materials undoubtedly do in many cases bear metals out of which ores are made. But in few instances are they ores as igneous rocks. Igneous rocks so rich in iron as to serve as ores have been found on a very small scale. Vogt[1] holds that certain sulphide ores are produced directly by processes of differentiation of igneous rocks; but while I do not deny this, I also would not unqualifiedly assent to it. However this may be, there is fair agreement on the part of all that the great mass of the metals which come from the igneous rocks are derived from them through the agency of underground water, and that the ores which are now worked by man are preponderantly concentrates from the igneous rocks, or from the sedimentary rocks, or from the two combined. But if some ores have directly solidified as magma, they do not come within the scope of the discussion tonight; for I said at the outset that only ores produced by underground water would be considered. Such ores are probably derived for the most part from the upper 10,000 meters of the crust of the earth.

My third premise follows directly from the considerations already given: *If the waters below the zone of fracture do not circulate vigorously, and if vigorous circulation by underground water be necessary in order that ore deposits be produced, it follows that the waters which perform this work are of meteoric origin.* They are the waters which fall from the clouds upon the earth and sink into it. I do not deny that some small part of water concerned in the production of ores may be derived from below the zone of fracture; I do not deny that the igneous rocks rising from below bring with them small amounts of water; but these amounts are insignificant — are inappreciable in quantity as compared with the vast amount of water which is necessary to do the work of ore deposition. We know to a certainty that the great mass of underground circulating waters are of meteoric origin. For instance, if a well be drilled at Chicago through the limestones and shales near the surface

[1] J. H. L. Vogt: Zeitschr, für prakt. Geol., January and April 1893, October 1894, April, September, November, December 1895.

into the sandstone below you know that great quantities of water issue. The water falls upon the ground far to the northwest in central Wisconsin, where the sandstone reaches the surface. It follows this pervious formation below impervious strata, and when the impervious strata are punctured at Chicago rises to the surface through the opening. So it is with artesian wells everywhere. I repeat, *The waters which we know to be vigorously circulating are of meteoric origin, and these are the waters which have deposited the ores.*

We are now ready to pass to the fourth of my premises, viz., *The movement of underground water is mainly due to gravitative stress.* This is perhaps so plain to you as engineers that it will hardly need proving; but certainly many men who have written about ore deposits have given other explanations. Why does the water rise in the artesian wells in Chicago? Simply because the level of underground water at the northwest where the sandstone is fed is at a higher elevation. The difference in elevation is only a few hundred feet; and yet the difference in the weight of the columns, or the force of gravity, is sufficient to drive the water underground through the sandstone for a hundred or more miles to Chicago and make it rise considerably above the level of Lake Michigan. If the deformation had been such that the porous formation had somewhere been depressed nearly to the bottom of the zone of fracture, and the openings did not thereby become smaller, this in no way would have lessened the speed of circulation. It is therefore clear from our knowledge of artesian wells that a very moderate head is entirely adequate to account for an underground lateral circulation of great length and for a vertical circulation of great depth—entirely adequate to account for it. If this be true, why should we appeal to subterranean heat or to the unknown mysterious forces at the depths as a main cause for underground circulation?

I do not deny that in some cases water is squeezed out of the rocks by orogenic movements, nor do I deny that heat produces an effect in underground circulation. We may suppose,

for instance, that the water entering at one point issues at another point at the same elevation, after following a deep underground path. Suppose the water during the journey comes in contact with volcanic rocks, or suppose the water becomes warmer as the result of the normal increase in temperature with increased depth. We will suppose, for the sake of simplicity, that the temperature of the water is 0° C. where it enters the ground, and at a temperature of 100° C. where it issues. This is an extreme case, and beyond the facts; but it makes the illustration simple. During its journey the water expands as a result of its rise in temperature, and a unit volume of the issuing water weighs only about 96 per cent. as much as does a unit volume the entering water. The cooler or descending column contains a greater mass of water than the ascending column; it is, therefore, pulled stronger by the force of gravity; and consequently circulation takes place. The descending column falls and the ascending column rises because of the gravitative stress.

In the case of the Chicago artesian wells we have seen that the flowage is due to differential gravitative stress resulting from difference in elevation. In the case we have just considered, we have seen that the flowage is due to differential gravitative stress occasioned by difference in temperature. Therefore, underground water circulation caused by gravitative stress may be initiated by difference in head or difference in temperature, or by both combined. Ordinarily difference in head and difference in temperature work together. Commonly water enters the ground at a higher level than it issues; and I think it can be shown that water which is descending is, upon the average, at a lower temperature than water which is ascending, although I cannot stop to fully discuss this point. Therefore the descending column is heavier. Hence, unequal gravitative stress, caused by difference in head and by difference in temperature, is the adequate cause to which I appeal to account for the circulation of underground water which does multifarious kinds of geological work, a small part of which is the deposition of ores.

It is now necessary to consider in some detail the manner in which underground water moves. For a long time I have realized that if underground water had a difference in head that it might penetrate to a great depth and rise again to the surface;

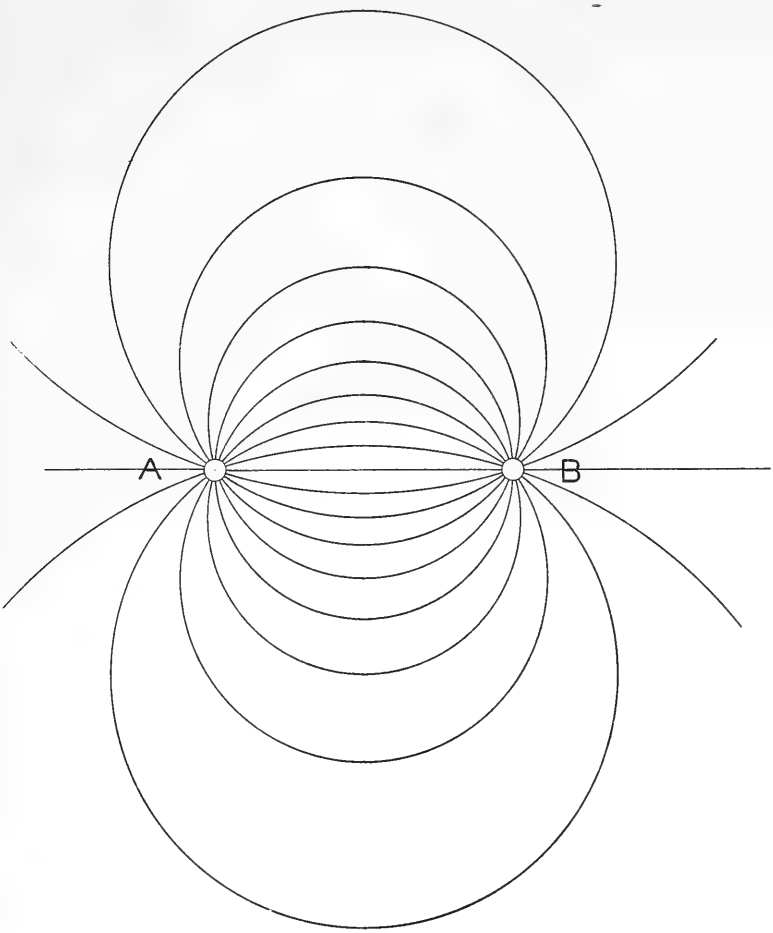

FIG. 1.

but I did not realize that it was not necessary to assume exceptional openings for such a circulation. I assumed that where such a circulation took place exceptionally favorable channels were available; but a recent paper by Professor Slichter[1]

[1] Theoretical Investigation of the Motion of Groundwaters, by C. S. SLICHTER, Nineteenth Ann. Rept. U. S. Geol. Surv., 1899, Pt. II, pp. 295–384.

upon the motion of groundwaters showed me that this was an entirely unnecessary assumption, and gave me the additional data needed upon this point. This chart (Fig. 1) is a horizontal diagram. A represents one well and B another well, separated by a homogenous porous medium. Into the well B, I pour water. In the well A there is no water at the outset; and the water flows from the well B to the well A through the medium. What is the path of the water? Its flowage is represented by the curved lines. Some of the water goes in a nearly direct course. Another part takes a somewhat curved course. Still other parts of the water follows a very indirect course, represented by the longer curved lines. All of the available cross section is utilized. If for instance this room were filled with water, and water were running in at one place in the front end of the room and were escaping at one place in the rear end of the room with equal speed, would the water simply follow the direct line between the two? You know perfectly well it would not. The entire available cross section of the room would be utilized, although the more direct course would be utilized to a greater extent than the more indirect course. This is intended to be illustrated on the chart (Fig. 1) by the lines representing the nearly direct courses being close together, and the lines representing the indirect courses being farther apart.

This chart (Fig. 1) then represents the horizontal circulation. If we pass to the vertical circulation the flowage is represented by this chart (Fig. 2). The water is being poured into the well B and passes to the well A. The water follows the course of the curved lines, so that with a difference in head equal to the difference in the level of the water in the two wells, a considerable part of the water being poured into B and passing through the homogenous porous medium to A penetrates a considerable depth, from which it rises and enters the well A. Now what will be the limit in nature of the downward search of underground water? We have already given it. Manifestly the lowest limit of effective circulation at any place is the bottom of the zone of fracture at that place. The zone of flowage

below is practically impervious. However, an impervious limiting stratum may exist at depths far less than the bottom of the zone of fracture. An impervious limiting stratum, perhaps a shale, may be found at a depth of 100 meters or less, or at any

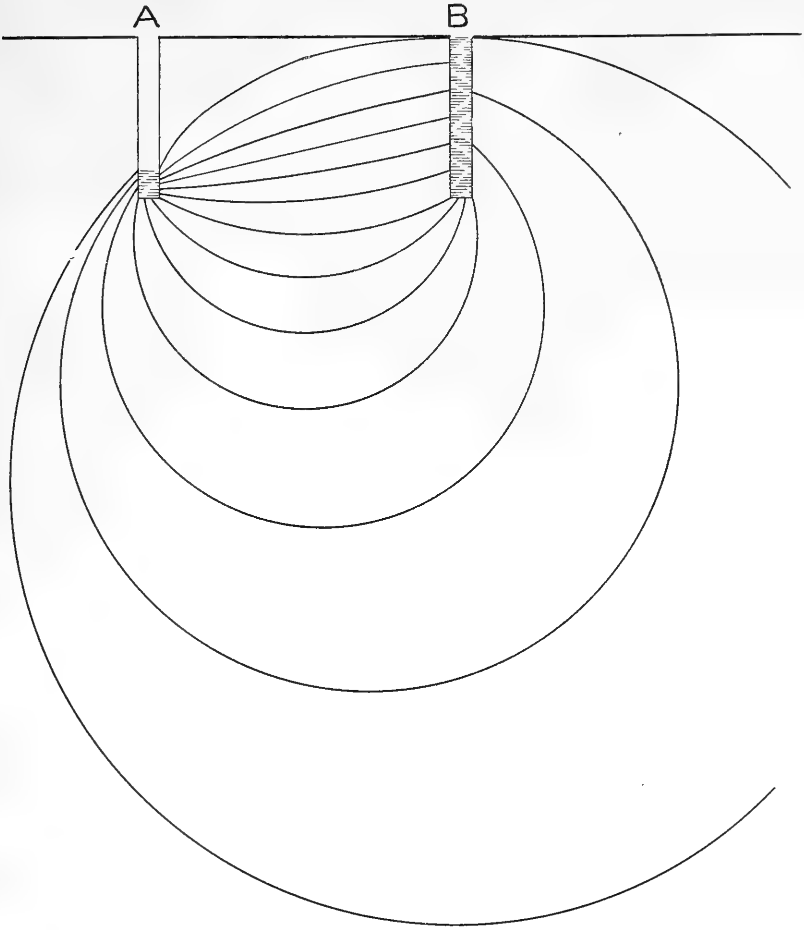

FIG. 2.

depth intermediate between this and the bottom of the zone of fracture for the strongest rocks. Where there are one or more pervious strata which are inclined and above, below, and between which are impervious formations, there may be two or more

nearly independent circulations. To illustrate, at Chicago the St. Peter's sandstone, the Potsdam sandstone, and even different parts of the Potsdam sandstone have more or less independent circulations. If a limiting stratum be supposed to be half-way down on the chart (Fig. 2) the lines of flow above this stratum would not be as they are now, but would be flatter and would be limited by the impervious rock.

Under natural conditions wherever there is an impervious rock there is a limit of some particular circulation in that direction. A limiting stratum may therefore be very near the surface, at the bottom of the zone of fracture, or at any intermediate depth; and theoretically a moderate head is sufficient to do the work of driving the water to any of these depths. Indeed, there is no escape from the conclusion that at least some circulation does occur in the deeper parts of the zone of fracture with a very moderate head. Of course in proportion as the head is great the circulation at depth is likely to be vigorous. But it may be objected that a deep circulation, while theoretically possible, must be exceedingly small in quantity, and consequently of comparatively little account in the deposition of ores. But the consideration of the underground circulation in reference to the Chicago artesian wells, shows that this objection has little weight. (See p. 737.) Moreover, the deeply circulating water, if less in quantity than that near the surface, takes a longer journey and is longer in contact with the rocks through which it is searching for the metals. Not only so, but it is at a higher temperature than the water at higher levels; and this also is favorable to taking mineral material in solution. And, finally, because it has a higher temperature it has less viscosity. While the variable viscosity of water is not so very important in reference to circulation in super-capillary tubes, in capillary tubes, which constitute a very large fraction of underground openings, and especially those at considerable depth, the viscosity is important —the flowage increasing directly as the viscosity decreases. The viscosity of water at 90° C. is only one fifth as much as it is at 0° C.; and therefore with a given head of water in capillary

tubes, if the temperature be considerably increased—and but a moderate depth is required to give considerable increase—the water moves several times as fast as it would at the surface under conditions similar in all respects save temperature. Therefore, because of these three factors, long journey, high temperature, and low viscosity, we cannot exclude the deep circulation from consideration. This circulation is indeed believed to be very important in the deposition of ores.

We are now prepared to consider the actual journey of underground water. Where water falls upon porous ground it finds innumerable openings through which it enters and begins its underground journey. This circulating water, as far as practicable, under the law of the minimum expenditure of energy, follows the paths of easiest resistance. But these are the larger openings, because resistance due to friction along the walls and within the current is very much less per unit circulation in large than in small openings. While therefore water enters the ground at innumerable small openings, as it goes down it more and more seeks the larger openings. Once found, it holds to them. The farther it continues its journey, the greater the proportion of the water which follows the larger openings. But if this be true, the water in its descending course is more likely to be widely dispersed and in the smaller openings; and in its upward course more likely to be concentrated and in the larger openings.

We can now follow the course of underground water in detail, but in doing this it is necessary to consider the elements of the problem separately. It is only by passing from a simple case to the very complex one of nature that we can understand the latter. Here is a chart (Fig. 3) which shows the surface of a slope, the level of groundwater, and the flowage of water in the simplest imaginable case. Below the level of groundwater all the openings in the rocks, great and small, are filled with water. The rocks are saturated. In the case represented I have supposed that all of the water enters at a single point, A; and that all of it issues at a single point, B. The curved lines represent the

flowage of the water through a homogeneous porous medium. In the next chart (Fig. 4) I have supposed water to enter at three points and issue at one; and I have supposed the flowage from each point of entrance to occur just as if no water were

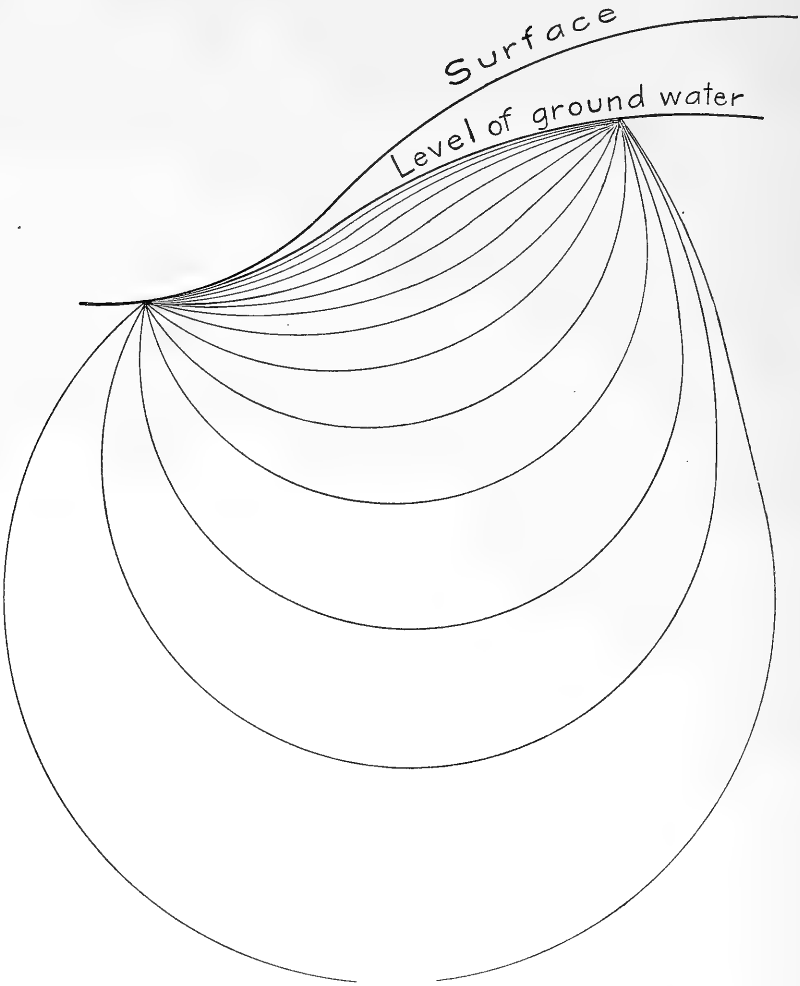

FIG. 3.

entering anywhere else, and therefore the systems of flowage to be superimposed. Of course this is not a real case. Underground water does not diverge from a single point and converge at another point in independence of the water entering

at other points. The water entering at innumerable points in vertical section and in horizontal section mutually interfere, and make the course for any given particle of water rather simple.

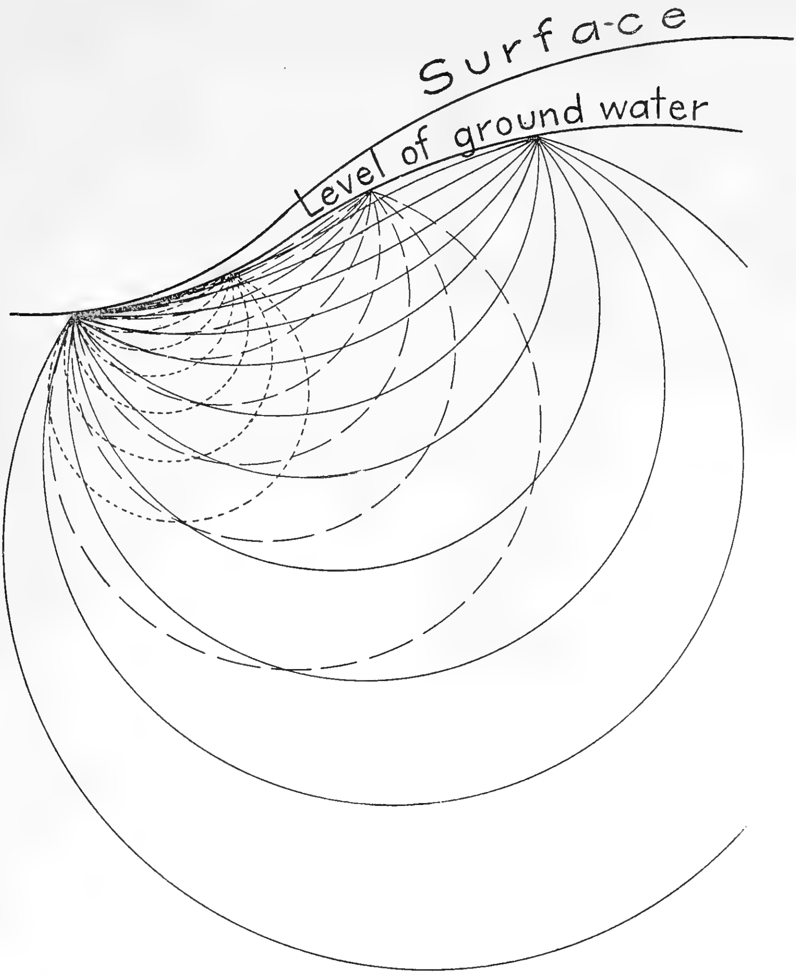

FIG. 4.

This I have tried to represent by another chart (Fig. 5). In this chart I have supposed particles of water to enter at equal horizontal intervals, and issue at a single point. You note that the water near the crest begins its journey by almost vertical

descent. In proportion as the entering water is near the valley the horizontal component becomes more important. The water near the valley follows a comparatively shallow course; but this water uses all the available space near the surface, and conse-

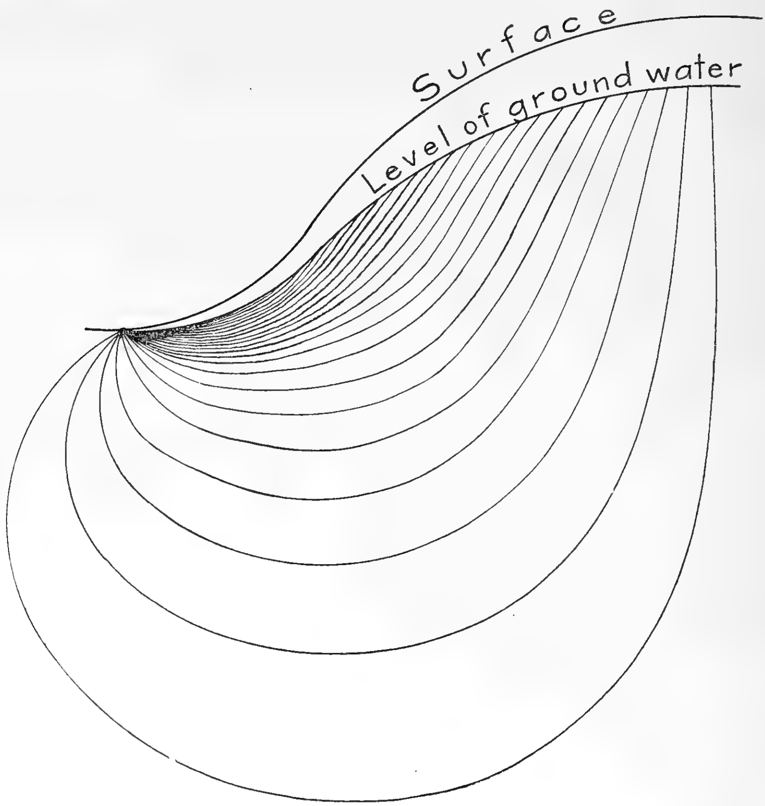

FIG. 5.

quently the water entering at the higher ground necessarily follows a long, circuitous, and deep course. The chart (Fig. 5) therefore represents the flowage with many points of entrance and a single point of exit, where there is interference of the circulating waters.

Thus far it has been supposed that the ground is uniformly porous, like an evenly grained sandstone without joint or fracture

of any kind, in which the water can go in all directions with equal ease. But absolute uniformity does not exist in nature. The openings in rocks are never of uniform size; they are never equally distributed. Suppose half way down the slope

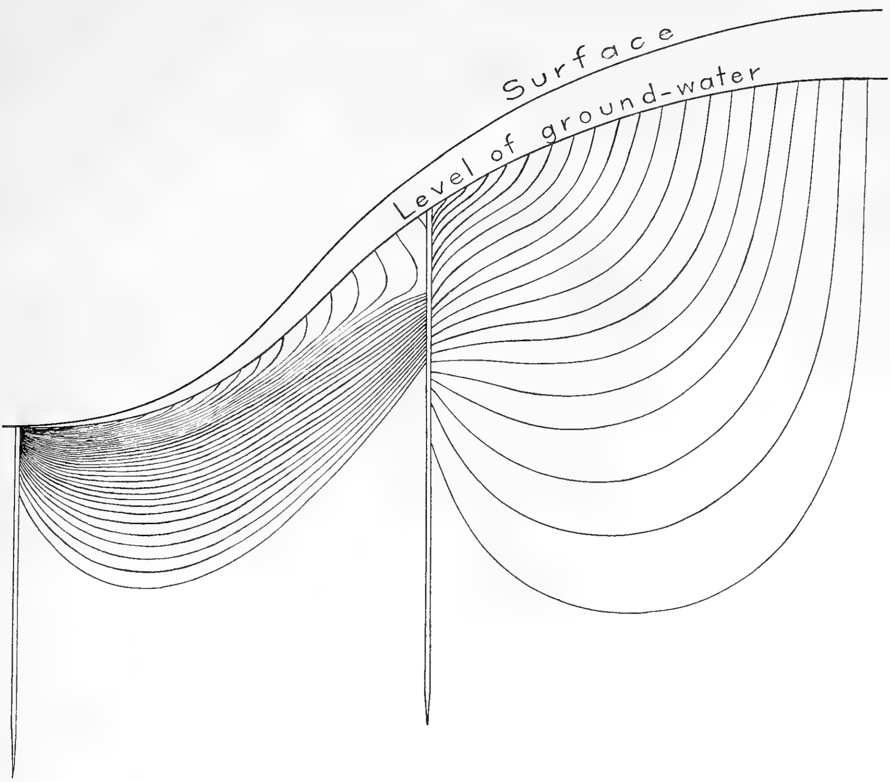

FIG. 6.

there is a vertical opening of unusual size transverse to the plane of the chart (Fig. 6), and another similar opening below the valley. If you please, we will call them fissures. These fissures, because large openings, will be fully utilized by the underground water. We readily see that groundwater will enter the higher fissure at many points and from various directions. Ordinarily it will enter the upper part while it is still descending; it will

enter the central part laterally; it will have begun its ascent before it enters the lower part. Therefore a fissure upon the middle of a slope will be very likely to receive water from above, from the side, and from below. But at a certain area of a fissure well up on the slope the water continuously received at the upper side of the fissure will escape laterally at the lower side. This water and that entering the ground below the upper fissure will make its way to the fissure below the valley. But here the level of groundwater is at the surface. Consequently all the water entering this fissure will ascend quite to the surface, and issue as a spring. If there be a fissure at the crest we can see that the descending water will go a long way down; but the waters will nowhere be ascending. If there be a fissure on the slope, both descending and ascending waters will ordinarily be active; although it is of course recognized that in fissures thus located the conditions may be such that the waters will ascend or descend only. If there be a fissure below a valley where the level of groundwater is at the surface the water will all be ascending; and there will be no descending water. At such places we have springs. Springs do not issue from the tops of mountains, but from slopes and valleys, most frequently the latter. Illustrating this are the Yellowstone Park springs of the Firehole River. The waters which feed the springs fall upon the crests and slopes of the mountains adjacent; on their way to the valley go deep below the surface, and at the Firehole ascend as hot springs and geysers. The water is driven by gravity due to a considerable head and the lower temperature of the descending column.

You are all doubtless aware that three theories are maintained as to the source of the waters which deposit ores. Some hold that the waters doing the work are descending; others that they enter laterally; others that they are ascending. The first is known as the descension, the second as the lateral secretion, and the third as the ascension theory. If my argument be correct as to a limit to the zone of fracture, fissures, as well as all other openings, must gradually become smaller and smaller,

and finally die out altogether. Water in a fissure may descend or may ascend for a considerable distance; but it is perfectly clear that, so far as fissures are concerned, except for the small amount entering the surface openings, the water must enter laterally. Consequently, if we apply the lateral-secretion theory broadly enough, we may say that all the waters which feed the fissures are lateral-secreting waters. But if we are descensionists, and consider only the upper part of a fissure on the slope—and that is what many very naturally have done because this is the part of the fissure most easily observed—we may say that the waters which are doing the work are descending waters. Or, if we are in such a district as that of the Comstock lode, in which are found great volumes of ascending water, we may say that the waters which are depositing the ores are ascending. All may be true. But in the past Sandberger held that lateral-secreting waters in the narrowest sense did all the work, and he refused to believe that ascending and descending waters were of importance; and Posepny held that ascending waters did nearly all the work, and gave small consideration to lateral-secreting and descending waters; whereas you see with perfect clearness that each theory is incomplete. Both are needed; they supplement each other.

Passing now to the work of underground water, we find there are very great differences in the nature of the work which takes place above the level of groundwater and below the level of groundwater. The first is called the belt of weathering; the second the belt of cementation[1] (see Fig. 7). Also there are great differences in the work which takes place in the zone of fracture, which includes both the belts of weathering and cementation, and that in the deep-lying zone, that of rock flowage. All of these differences have a very close bearing upon some phase of ore deposition. But the subject is too complex for me to take up fully, and I shall simply give the major differences in the reactions without stopping to demonstrate their

[1] Metamorphism of Rocks and Rock Flowage, by C. R. VAN HISE: Bull. Geol. Soc. Am., Vol. IX, p. 278.

correctness.[1] Above the level of groundwater, in the belt of weathering, the chemical reactions of oxidation, carbonation, hydration, and solution are the rule. The mechanical results are disintegration, softening, and decomposition of the rocks. Below the level of groundwater, in the belt of cementation, the chemical reactions of oxidation and carbonation are less active; but hydration occurs very extensively. Instead of solution, deposition is continually taking place. The mechanical result is that the rocks, instead of being disintegrated, softened, and decomposed, are hardened, the openings being cemented. Where comes the material for cementation? Why, from this belt of weathering

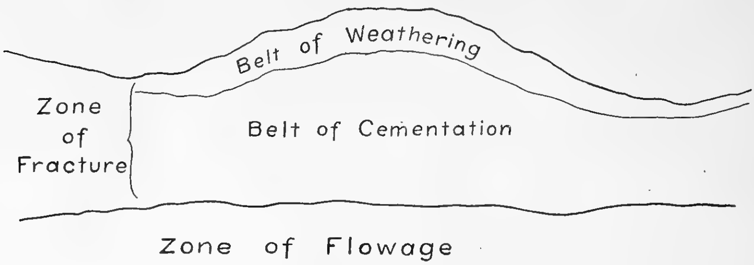

Fig. 7.

above, where solution is taking place. If the waters in the belt of weathering are continuously taking materials into solution, and are continuously depositing material below, as denudation goes on these belts steadily migrate downward. The present belt of weathering not long ago geologically was in the belt of cementation. While, therefore, the belt of weathering at any given time in the past, as now, was relatively thin, it may have moved downward for thousands of feet. In many mining districts it is estimated that from 1000 to 3000 or more meters of rock have been removed from above the present surface. All of this thickness has been in the belt of weathering; although at any one time the belt of weathering may have been but a score or few score meters in thickness. Therefore, from the belt of weathering a great and adequate amount of material may

[1] For a fuller discussion see Metamorphism, cit., pp. 277–286.

have been derived to fill the cracks and crevices of the entire belt of cementation below, although this belt may be thousands of meters thick. This process of filling cracks and crevices by deposition is the general law for the great belt of cementation below the level of groundwater, just as certainly as solution is the general law for the belt of weathering above the level of groundwater. These are the dominant processes. However, I by no means assert that deposition does not occur in the belt of weathering, and that solution does not occur in the belt of cementation. Indeed, the solution of material in various places, in both the belts of weathering and cementation, and the deposition of this same material or a part of it in the same belts at other places are very important processes.

We therefore conclude that the solution of material in the belt of weathering and the deposition of material in the belt of cementation, and the solution and deposition of material within the same belts, fills the openings in the rocks below the level of groundwater. These processes are gradually changing the soft sandstones, such as exist below the surface limestone of Chicago, into quartzite. By the same processes fractures—small and great, from minute joints to great fissures—are filled by deposition of material from underground waters. The formation of ore deposits is largely an incident of this process. The volume of material transported from the belt of weathering and deposited below in the openings of the belt of cementation, and transferred from place to place within these belts, is many million times greater than the ore deposits. The development of ores is merely an exceptional case of a widespread and most important geological process, the deposition of ores involving only a consideration of the particular materials which are of value to man. This evening I propose very briefly to discuss the source of such materials: how they are carried; why and where they are deposited. The particular case is under the general laws which control the general process of solution and deposition.

There are a great many chemical laws which affect the process of ore deposition, and a few of them I am obliged to

mention. The first law is: All the elements and compounds of nature are soluble to some extent in water. If water be placed in contact with an hundred substances, it will hold some part of every one of those substances in solution. It follows that if, in the journey of underground water, it finds here and there gold or silver or lead or zinc or iron, in quantity small or great, those materials to some extent will be taken into solution. The second law is the fundamental principle of chemical dynamics, viz.; Chemical action is proportional to the active mass. To illustrate, other things being equal, the greater the quantity of a compound present, the greater the quantity which will be taken into solution and deposited from solution.

The materials will be likely to be taken into solution in large measure during the descending course of the water; and deposited from solution in large measure during the ascending course of the water. For this there are a number of reasons. First, solution is likely to occur during descension because the conditions are those of increasing temperature and pressure. It is well known that increase of temperature greatly increases the solvent power of water. In many cases a slight rise in temperature is sufficient to increase this activity in an amazing degree; in fact out of all proportion to the increase of temperature. Deposition is likely to occur during ascension because the conditions are those of decreasing temperature and pressure.[1] Second, some substances are held in solution better than others. Certain substances, such as quartz, may be deposited during the downward course of the water, and a more soluble substance, such as gold, silver, or some other substance, be dissolved at the same time. Third, the larger openings, such as fissures, are the trunk channels of water circulation. In them the waters from different sources mingle; and this to my mind is the most important single factor—probably the dominant factor,

[1] The relations of temperature and pressure to solution and precipitation are much more complicated than implied in the above general statement. For a more nearly exact expression of the facts see Some Principles Controlling the Deposition of Ores, by C. R. VAN HISE: Separate from Trans. Am. Inst. Min. Engineers, Vol. XXX, 1900, pp. 38–43.

in the precipitation of ores. If the contents of half a dozen test tubes filled with solutions chosen at random be dumped together, a precipitate is almost sure to form. And just so sure as underground waters come from this source and that source and mingle in the trunk channels of underground circulation, just so surely are precipitates formed. Fourth, in the formation of an ore deposit the wall rock may contribute a solution which precipitates a metal, or it may contribute a metal which is precipitated by a solution. Consequently an ore deposit may be confined to a particular horizon where there is a certain rock. For instance, lead and zinc are very generally associated with limestone, and the sandstones or other rocks above or below are very likely to be deficient or nearly devoid of these metals. To a less extent other ores show a decided preference for limestone as compared with other rocks. The explanation may be that the limestone itself furnishes the material; and this is believed to be the fact in various cases. The explanation may be that the limestone furnishes a precipitating agent to solutions derived from other rocks. It may be that the limestone because of its ready solubility furnishes large openings in which big deposits may be formed. Finally the explanation may lie in the combination of two or more of these factors. I have no doubt if we consider the whole world each of these factors is important, and that in some cases all of them coöperate. As a result of the combination of the various factors above considered a porous rock or an opening once in a million or ten million times receives enough of the metallic materials in solution so that a fraction of an ounce of gold per ton, or a few ounces of silver per ton, or a few per cent. of copper or some other metal, or a large per cent. of iron, will be precipitated; and we call the material an ore deposit. An ore deposit it is from an economic point of view. From a geological point of view it is usually to a far greater extent quartz and calcite and other gangue minerals.

I wish now to go a little further and consider the fissure on the slope shown in this chart (Fig. 6), both in the past and the

present. At some distant time in the past suppose the surface and level of groundwater, instead of being as shown, were at much higher levels, having since been greatly lowered by the processes of denudation. Where would the upper part of the fissure shown, the water of which is descending, be with reference to the circulation at that time? It would be where the lower part of the fissure now is, would it not? It would be where the waters are ascending, as shown in the lower part of the fissure. Therefore for the part of the fissure where the water is now descending it may be that the first contribution of ore was made by ascending waters, although descending waters are now the only important factor. But as denudation went on the condition would gradually change. The part of the fissure under consideration would pass through a stage in which the waters would mainly come in laterally. As denudation went still farther the waters might all be descending, and in the extension of the fissure below the waters might come in laterally, and still deeper might be ascending. We must now still further amplify our theory, must we not? To explain the entire ore deposit we have to consider all parts of the ore deposit throughout its entire history. At present ore deposition by descension, by lateral secretion, by ascension, is somewhere occurring in the fissure; but not only is this the case, but all have worked in turn in the upper part of the deposit. Therefore this further complicates the theory of ore deposition.

Now I wish to give some facts as to the actual occurrences of ore deposits before I go to the next step in theory. At Butte, Mont., are famous copper deposits. In the copper lodes of this district, in the very upper part of the deposits, above the level of groundwater, there were oxidized ores which carried high values in silver and gold, but very low values in copper. At and a short distance below the level of groundwater there were very high values in copper as sulphides. "There follows below a region of varying height, of valuable rock, which again slowly deteriorates in depth; this deterioration, however, being so retarded finally as to be scarcely

appreciable."[1] This deep ore is mainly copper-bearing pyrites. Douglass tells us that in depth every copper deposit of the entire Appalachian region of the United States shows only cupriferous pyrrhotite. An excellent illustration is Ducktown, Tenn., where at the level of groundwater was a very rich deposit of chalcocite but a few feet thickness which rapidly changed into very low grade cupriferous pyrrhotite.[2] In Australia down to the level of groundwater are high values in native gold; below the level of groundwater are auriferous pyrites bearing relatively small values of the precious metals.[3] Some of the superintendents say where ounces of gold are found above the level of groundwater only pennyweights are found below.[4] In the Sierra Nevada of the United States, according to Lindgren,[5] above the level of groundwater the gold values ran from $80 up to $300 per ton; but below the level of groundwater where there are sulphurets the values average from $20 to $30 per ton. Notwithstanding the fact that occurrences such as those mentioned are typical of the ore deposits of many districts of the world it has been believed by very many practical mining men that ore deposits become richer upon the average with increase of depth; but it must be admitted that the facts do not justify this sanguine expectation. In fact nine mines out of ten, taking the world as a whole, are poorer the second 300 meters than they are the first 300 meters, and are poorer the third 300 meters than they are the second 300 meters. In fact, many

[1] The Ore Deposits of Butte City, by R. C. BROWN: Trans. Am. Inst. Min. Eng., Vol. XXIV, 1895, p. 556.

[2] The Persistence of Lodes in Depth, by W. P. BLAKE: Eng. Min. Jour., Vol. LV, 1893, p. 3.

The Ducktown Ore Deposits and Treatment of the Ducktown Copper Ore, by C. HENRICH: Trans. Am. Inst. Min. Eng., Vol. XXV, 1896, pp. 206–209.

[3] The Alterations of the Western Australian Ore Deposits, by H. C. HOOVER: Trans. Am. Inst. Min. Eng., Vol. XXVIII, 1899, pp. 762–764.

[4] The Genesis of Certain Auriferous Lodes, by J. R. DON: Trans. Am. Inst. Min. Eng., Vol. XXVII, 1898, p. 596.

[5] The Gold-quartz Veins of Nevada City and Grass Valley, California, by WALDEMAR LINDGREN: Seventeenth Ann. Rep. U. S. Geol. Surv., 1895–6, Pt. II, p. 128, 1896.

ore deposits have been exhausted or have become so lean as not to warrant working before the 300 meter level is reached; a large proportion before the 600 meter level is reached; while comparatively few ore deposits have been found to be so rich as to warrant working at depths greater than 1000 meters.

There are however some ore deposits which are not known to decrease in richness with depth so far as yet exploited. There are a considerable number of deposits in which after a first rapid decrease in richness maintain their tenor pretty well to the depth of 300, 500 or even 1000 meters, and some few deposits maintain their richness at even greater depths. But we cannot reasonably hope that a deposit will get richer with depth provided we use a 300-meter unit for measurement. The most sanguine view which is ever justified for any deposit is that, using a 300-meter unit, that the second shall be as good as the first, and the third as good as the second. While the above is true there are very great irregularities in the richness of ore deposits, both favorable and unfavorable, due to multifarious causes, which I cannot possibly discuss tonight, but which I considered somewhat fully in the Institute paper.[1] These irregularities are especially marked in the upper 300 meters of a deposit; so that in many cases if the unit of measurement were 10 meters or 30 meters, or in a few cases 100 meters even, it might be said that deposits are becoming richer with depth; although the reverse also occurs in many cases. The truth is that in the uppermost part of an ore deposit the variations in richness with depth are extreme, and no definite rules can be laid down in reference to them.

Now what is the explanation of these irregularities and of the very general diminution of richness with depth? What is the explanation in some cases of the relatively even values at variable depth? The last question will be first considered.

In those instances in which the tenor is maintained or practically maintained from the surface to a great depth the ore

[1] Some Principles Controlling the Deposition of Ores, by C. R. VAN HISE: Trans. Am. Inst. Min. Eng., Vol. XXX, 1900, pp. 102–112.

is believed to be the result of a single concentration by ascending waters. Such ore deposits may continue without any appreciable diminution in richness to the lowest limits to which man may expect to penetrate the earth; but these are exceptional cases. Even ore deposits which are the result of a single concentration by ascending water may diminish in richness at considerable depth. It has been seen that in the fissure at the bottom of the valley on this chart (Fig. 6) that the water ascends to the surface. It is evident that the upper part of the fissure receives the greatest supply of water, and this water to a large extent does not penetrate any great depth; while the lower part of the fissure receives less water, but this water penetrates to a considerable depth. It may happen that the water relatively near the surface traverses the rocks containing the main supply of metals and therefore brings the chief contributions of valuable material, or such waters may carry the precipitating agent. In such instances the ore deposits produced by ascending water alone, would diminish in richness with depth; but such decrease would not be likely to be very rapid. Upon the other hand, if the above conditions be reversed, a deposit may increase in richness for a considerable depth; but as a matter of fact this appears to be a very infrequent case.

As illustrations of the ore deposits of the class produced by ascending waters alone are the copper deposits of Lake Superior. These deposits, while very bunchy and extremely irregular in the distribution of copper, are wonderfully persistent in depth. The copper of the ore was deposited in the metallic form. As compared with sulphides, this material is not readily oxidized. In this district the rocks above the level of groundwater are not appreciably weathered. Doubtless there was a belt of weathered material before the glacial epochs, but if so, it has been swept away by ice erosion; and since the glacial period sufficient time has not elapsed to weather appreciably the rocks which now lie within the theoretical belt of weathering. If there once were in this district an upper belt of weathering in which there were deposits of exceptional richness, this

material has been removed. However, in this district, a first concentration by ascending waters was adequate, but it is not often that a first concentration produces deposits of such richness as those adjacent to Calumet and Houghton on Keweenaw Point; and, indeed, this is exceptional even in the Keewenawan of the Lake Superior region; for while concentrations of copper have occurred at many points in the rocks of this period, as yet at no other locality have those concentrations been found to be so abundant and rich as to warrant exploitation on a large scale.

I now turn to the question as to the cause of frequent diminution of richness of ore deposits with depth. Many or most of such ore deposits are believed to be the products of two concentrations, the first by ascending, the second by descending waters. In this connection it is necessary to call attention to the fact that a large proportion of the ore deposits which are being exploited are below some part of a slope. It may be said that the reason for this is that the low grounds are more difficult to explore and work; but giving due allowance for this, it still seems to me that the majority, perhaps the great majority, of very rich deposits are below slopes and crests, and not below the valleys. I believe the richer deposits are below the slopes, because at these places a second concentration is possible and probable.

Returning now to this chart (Fig. 6) we shall direct our attention to the fissure on the slope. This fissure once extended up through the overlying rocks which have been removed by denudation. What has become of the ore in the part of the fissure which has been worn away? If, for instance, it carried 5 per cent. of copper, what has become of it? A part of it would have been scattered far and wide through erosive action; but a part of it would have been taken into solution and redeposited in the same vein deeper down. In the belt of weathering oxidized salts, such as sulphates, would form; the descending waters would carry these products downward; and it is my belief that they would react upon the solid, lean sulphides below with the result of precipitating the metals from the descending solutions.

Now this has been held to be a mere unverified assumption by some geologists, but it seems to me that they have not fully considered the certain effects of the chemical laws concerned. We know if in a laboratory a solution of copper sulphate or other copper salt be placed in contact with iron sulphide, that copper will be thrown down as copper sulphide. If the copper solution be placed in contact with a lean copper-iron sulphide, a sulphide richer in copper will be produced. And if these reactions occur in the chemical laboratory, will they not as certainly occur in the laboratory of nature, although perhaps more slowly?

At this point it is to be recalled that in many copper deposits above the level of groundwater oxides and carbonates occur, while below the level of groundwater are sulphides. Moreover, at high levels these sulphides are rich in copper, and they usually become poorer in copper sulphide and richer in iron sulphide at the lower levels. You will remember at Butte, Mont., at and for a distance below the level of the groundwater, are rich copper sulphurets which grade at depth into leaner copper sulphides containing correspondingly large amounts of iron sulphide. You will remember the same is true for the entire Appalachian region. You will remember that frequently above the level of groundwater gold lodes are exceedingly rich. What is the explanation of these and similar facts? What is the explanation of the exceptional or even extraordinary richness of the deposits at and near the level of groundwater, and of the low grade of cupriferous pyrites deep below the level of groundwater. In my opinion the only plausible explanation is that the rich parts of the deposits have received two concentrations, the first by ascending waters and the second by descending waters. The metals of the rich portions of the deposits were largely contributed by the parts of the deposit above, or once above, the rich parts. In some cases portions of the depleted veins remain, as at Butte; but frequently the depleted parts of the veins have been removed by erosion. The remote source of the material was, therefore, the metals deposited by the first concentration.

But let us follow the matter still farther. In the majority of cases, as denudation continued, the parts of the ore deposits produced by the second concentration rise into the belt of weathering. They may there be partly or wholly transformed into rich oxidized products, or they may be depleted to extend the rich deposits below. In the concentration by descending waters the chief chemical reactions are believed to be between the oxides or salts of copper and the sulphide of iron. The precipitation of copper sulphide resulting may occur in various ways.

The reaction may produce chalcopyrite, as shown by the following equations:

$CuSO_4+2FeS=CuFeS_2+FeSO_4$, or
$CuSO_4+2FeS_2+O_4=CuFeS_2+FeSO_4+2SO_2$.

The reactions may produce bornite, as shown by the following equations:

$Cu_2SO_4+CuSO_4+3FeS=Cu_3FeS_3+2FeSO_4$, or
$Cu_2SO_4+CuSO_4+3FeS_2+6O=Cu_3FeS_3+2FeSO_4+3SO_2$.

Or the reactions may directly produce chalcocite, as shown by the following equations:

$Cu_2SO_4+FeS=Cu_2S+FeSO_4$, or
$Cu_2SO_4+FeS_2+O_2=Cu_2S+FeSO_4+SO_2$.

If the reactions are between a copper salt and sulphide bearing copper various reactions throwing down the copper may also occur. The reactions may be upon chalcopyrite producing bornite, as shown by the following equation:

$2CuFeS_2+CuSO_4+O_2=Cu_3FeS_3+FeSO_4+SO_2$.

It may be the reaction of copper sulphate upon chalcopyrite or bornite producing chalcocite, as shown by the following:

$CuFeS_2+CuSO_4+O_2=Cu_2S+FeSO_4+SO_2$, or
$Cu_3FeS_3+CuSO_4+O_2=2Cu_2S+FeSO_4+SO_2$.

It may be by the reaction of copper oxide or copper sulphate upon covellite producing chalcocite, as shown by the following equations:

$6CuS+2Cu_2O=5Cu_2S+SO_2$, and
$6CuS+2Cu_2SO_4+3H_2O=5Cu_2S+2H_2SO_4+H_2SO_3$.

Parallel sets of reactions could be, and indeed are written in my full paper upon the subject of ore deposits, which explain the formation of the rich sulphides of lead, zinc, and silver through the reactions of the oxidized products of these metals upon sulphide of iron, producing rich sulphides of lead, zinc, and silver. However time does not suffice to present these this evening. The particular reaction in an individual case will depend upon the relative solubilities of the various compounds present, upon the law of mass action, upon the pressure and temperature, and upon various other factors.

Now I do not assert of the equations which have been written for copper and the other metals that the reactions represented occur exactly as written, but I do assert that reactions of the general character represented occur by which the oxidized products of the metals in solution are thrown down by the lean sulphurets, producing rich sulphurets. I have no doubt that many other reactions besides those written take place. It is exceedingly difficult to ascertain the particular reactions which occur at a given time and place; but I think it is perfectly clear that reactions occur of the type of those written. I cannot attempt to give you all the evidence on the point, but to me the case is demonstrative. If this be correct we now have an explanation of the fact that a great many ore deposits are rich at high levels and become poorer with depth. These ore deposits have undergone two concentrations, a first concentration deposited by ascending waters and a second concentration deposited by descending waters. The supplies for the first concentration were obtained from the widely dispersed and small amounts of material disseminated through the rocks. The supplies for the second concentration were derived from an earlier concentration.

In the foregoing statements the second concentration of metals by solution, downward transportation, and precipitation by reactions upon the sulphides of an earlier concentration has been emphasized. However, it is not supposed that this is the only process which may result in enrichment of the upper parts of ore-deposits by descending waters. The enrichment of this

belt may be partly caused (1) by reactions between the downward moving waters carrying metallic compounds and the rocks with which they come in contact, and (2) by reactions due to the meeting and mingling of the waters from above and the waters from below.

(1) The metallic compounds dissolved in the upper part of the veins, carried by descending waters, may be precipitated by material contained in the rocks below. This material may be organic matter, ferrous substances, etc. So far as precipitating materials are reducing agents, they are likely to change the sulphates to sulphides, and precipitate the metals in that form. While sulphides may thus be precipitated either above or below the level of groundwater, they are more likely to be thrown down below the level of groundwater. Other compounds than reducing agents or sulphides may precipitate the downward moving salts in other forms than sulphides.

(2) In a trunk-channel, where waters ascending from below meet waters descending from above, there will probably be a considerable belt in which the circulation is slow and irregular, the main current now moving slowly upward and now moving slowly downward, and at all times being disturbed by conventional movements. Doubtless this belt of slow general movement and conventional circulation would reach a lower level at times and places of abundant rainfall than at other times and places, for under such circumstances the descending currents would be strong. The ascending currents, being controlled by the meteoric waters falling over wider areas, and subject to longer journeys than the descending currents, would not so quickly feel the effect of abundant rainfall. Later, the ascending currents might feel the effect of the abundant rainfall and carry the belt of upward movement to a higher level than normal. However, where the circulation is a very deep one, little variations in ascending currents result from irregularities of rainfall.

In the belt of meeting ascending and descending waters (see Fig. 6) conventional mixing of the solutions due to difference in temperature would be an important phenomenon. The waters

rom above are cool and dense, while those from below are warm and less dense. In the neutral zone of circulation the waters from above would thus tend to sink downward, while waters from below would tend to rise, and thus the waters would be mingled. Still further, even if the water were supposed to be stagnant at the neutral belt, it is probable that by diffusion the materials contributed by the descending waters would be mingled with the materials contributed by the ascending waters.

Ascending and descending solutions are sure to have widely different compositions, and precipitation of metalliferous ores is a certain result. As a specific case in which precipitation is likely to occur, we may recall that waters ascending from below contain practically no free oxygen and are often somewhat alkaline, while waters descending from above are usually rich in oxygen and frequently contain acids, as at Sulphur Bank, described by Le Conte.[1] The mingling of such waters as these is almost sure to result in precipitation of some kind. Le Conte further suggests[2] by the mingling of the waters from below with those from above that the temperature of the ascending column will be rapidly lessened, and this also may result in precipitation, but the dilution would work in the reverse direction.

The metals precipitated by the mingling of the waters may be contributed by the descending waters, by the ascending waters, or partly by each. In so far as more than an average amount of metallic material is precipitated from the ascending waters, this would result in the relatively greater richness of the upper part of veins independently of the material carried down from above.

In all the cases considered the precipitation and enrichment of the upper parts of deposits follow from the reactions of downward moving waters. Their effect may be to precipitate the metals of the ascending water to some extent and thus assist in the first concentration. But the results of these processes

[1] On the Genesis of Metalliferous Veins, by JOSEPH LE CONTE: Am. Jour. Sci., 3d ser., Vol XXVI, 1883, p. 9.

[2] LE CONTE, op. cit., p. 12.

cannot be discriminated from the concentration resulting from an actual downward transportation of the material of an earlier concentration. In concluding this part of the subject, *It is held that the downward transportation of metals already in lodes is the most important of the causes explaining the character of the upper portions of ore deposits; and that their peculiar characters are certainly due to the effect of descending waters.*

The concentrations by ascending and descending waters have been considered as if they were mainly successive. In some instances this may be the case; but it is much more probable that ascending and descending waters are ordinarily at work upon the same fissure at the same time, and that their products are, to a certain extent, simultaneously deposited. For instance, under the conditions represented by this chart (Fig. 6) a first concentration by ascending waters is taking place in the lower part of the fissure, and a reconcentration by descending waters is taking place in the upper part of the fissure. Between the two there is a belt in which both ascending and descending waters are at work. The rich upper part of an ore deposit which is worked in an individual case may now be in the place where ascending waters alone were first acting, where later, as a consequence of denudation, both ascending and descending waters were at work, and still later, where descending waters alone are at work. The more accurate statement concerning ore deposits produced by ascending and descending waters, is, therefore, that ascending waters are likely to be the potent factor in an early stage of the process, that both may work together at an intermediate stage, and that descending waters are likely to be the potent factor in the closing stage of the process.

Also, for the sake of simplicity in the consideration of the concentrations I have disregarded the lateral elements of the moving water. In many cases superimposed upon the vertical movements in the fissures or other openings are lateral movements, as a result of which the deposits instead of being in vertical positions are inclined, often much inclined, and indeed may be horizontal or even locally descending. Moreover the

horizontal extents of the deposits may be much greater than the vertical extents. Reduced to a simple and broad statement, *The first concentration of many ore deposits is the work of a relatively deep water circulation, while the reconcentration is the result of reactions upon an earlier concentration through the agency of a relatively shallow water circulation. Commonly the deep water circulation is lacking in free oxygen and contains reducing agents, and the shallow water contains free oxygen. The deep water is therefore a reducing, and the shallow water an oxidizing agent.*

In addition to the general factors already considered there are many special factors which have a most important, indeed, very often a controlling influence in the production of ore-chutes and in the localization of ore in certain areas and districts. Some of these factors are the complexity of openings, the presence of impervious strata at various depths, the presence of pitching folds, the character of the topography. I see however that my time is nearly gone, and I shall not take up their discussion this evening, but must refer those especially interested in this phase of the subject to my full paper already repeatedly mentioned.[1] I must however note that impervious strata are frequently of controlling importance in the underground circulation. Often deep and shallow water circulations are separated by such strata. Often also as the result of the removal of impervious strata by denudation, the previous deep circulation ceases and the action of the shallow circulation is inaugurated.

At this point it may be well to briefly recall the most fundamental features of the water circulation which produces the ore deposits. First comes the downward-moving, lateral-moving waters of meteoric origin which take into solution metalliferous material. These waters at depth are converged into trunk channels, and there, while ascending, the first concentration of ore deposits may result. After this first concentration many of the ore deposits which are worked by man have undergone a later concentration not less important than the earlier, as a result of

[1] Some Principles Controlling the Deposition of Ores, by C. R. VAN HISE : Trans. Am. Inst. Min. Eng., Vol. XXX, 1900, pp. 112–146.

shallow descending or lateral-moving waters. In other cases a concentration by descending, lateral-moving waters alone is sufficient to explain some ore deposits. It thus appears more clearly than heretofore that an adequate view of ore deposits must not be a descending-water theory, a lateral-secreting water theory, or an ascending-water theory alone. While an individual ore deposit may be produced by one of these processes, *For many ore deposits a satisfactory theory must be a descending, lateral-secreting, ascending, descending, lateral-secreting theory.*

But there is no question in my mind that this theory is still insufficient to fully explain many of the ore deposits. No knowledge is ever complete. We move step by step, carrying a theory nearer and nearer completion. If, however, a theory be based on good work, it usually will not prove to be false; it will be found to be incomplete. Sandberger was not wrong when he said lateral secretion explained many things in reference to ore deposits. He was wrong only when he excluded other factors. He became unscientific when he carried his theory further than his observations justified. While the theory here proposed is believed to make an important advance, it will sooner or later be found to be incomplete. I trust it will not be found to be false. But the most that I can hope for it is that it is approximately correct as far as it goes.

It is believed that the principles which have been presented lead to a new and natural classification of the ore deposits produced by underground water. As already noted, ore deposits may be divided into three groups: (1) ores of igneous origin, (2) ores which are the direct result of the processes of sedimentation, and (3) ores which are deposited by underground water.

Since the ores produced by igneous agencies and those produced by processes of sedimentation have not been considered in this paper, a subdivision of these groups will not be attempted.

Ores resulting from the work of groundwater, group (3) above, may be divided into three main classes:

(*a*) Ores which at the point of precipitation are deposited by ascending waters alone. These ores are usually metallic or

some form of sulphuret; but they may be tellurides, silicates, or carbonates.

(*b*) Ores which at the place of precipitation are deposited by descending waters alone. These ores are ordinarily oxides, carbonates, chlorides, etc., but silicates and metals are exceptionally included.

(*c*) Ores which receive a first concentration by ascending waters and a reconcentration by descending waters. The concentration by ascending waters may wholly precede the concentration by descending waters, but often the two processes are at least partly contemporaneous. The materials of class (*c*) comprise oxides, carbonates, chlorides, and rarely metals and silicates above the level of groundwater, and rich and poor sulphurets, tellurides, metallic ores, etc., below the level of groundwater. At or near the level of groundwater, these two kinds of products are more or less intermingled, and there is frequently a transition belt of considerable breadth.

How extensive are the deposits of class (*a*) I shall not attempt to state. Indeed, I have not such familiarity with ore deposits as to entitle me to an opinion upon this point. However a considerable number of important ore deposits belong to this class. This class is illustrated by the Lake Superior copper deposits.

The ore deposits of class (*b*) are important. Of the various ores here belonging probably the iron ores are of the most consequence. A conspicuous example of deposits of this kind are the iron ores of the Lake Superior region.

It is believed that the ore deposits of class (*c*) are by far the most numerous. I suspect that a close study of ore deposits in reference to their origin will result in the conclusion that the great majority of ores formed by underground water are not the deposits of ascending waters alone, but have by this process undergone an early concentration, and that descending waters have produced a later concentration, as a result of which there is placed in the upper 50 to 500 or possibly even 1000 meters of an ore deposit a large portion of the metalliferous material

which originally had, as result of the early concentration, a much wider vertical distribution.

To the foregoing classification objections will at once be made: It will be said that there are no sharp dividing lines between the groups and classes. To this objection there is instant agreement. Transitions are everywhere the law of nature. It is well known that there are gradations between different classes of rocks,[1] and this statement applies equally well to ore deposits. I even hold that there is gradation between ore deposits which may be explained wholly by igneous agencies and those which may be explained wholly by the work of underground water or by processes of sedimentation.

I have elsewhere held that there is complete gradation between waters containing rock in solution and rock containing water in solution.[2] If there be no sharp separation between water solutions and magma it is probable that this is also true in reference to ore deposits of direct igneous origin and those produced by underground water. There may be ore deposits in which water action and magmatic differentiation have been so closely associated that one cannot say whether the resultant ore deposit is mainly a water deposit or mainly a magmatic deposit. But for the vast majority of ore deposits, if I properly apprehend the relations, the broad general statements which I have made apply. Ordinarily there is little difficulty in discriminating between veins and dikes, the first representing crystallizations from water solutions, the second crystallizations from magma. There are few cases where the discrimination in reference to ore deposits is not easy. While gradations between water deposited ores and igneous ores are uncommon, gradations between the different classes of ore deposits formed by underground water are common.

Ores which have received a first concentration by igneous agencies or by processes of sedimation are sure to be reacted upon by the circulating underground waters, and thus a second

[1] The Naming of Rocks, by C. R. Van Hise: Journ. of Geol., Vol. VII, 1899, pp. 687, 688.

[2] Principles of North American pre-Cambrian Geology, by C. R. Van Hise: Sixteenth Ann. Rept. U. S. Geol. Surv., 1894–5, Pt. I, p. 687.

or even a third concentration may take place. The first concentration by igneous or sedimentary processes may be the more important or dominant process, or the additional concentration or concentrations by underground waters may be the more important or dominant process. In some cases therefore the ores may be referred to as produced by igneous agencies, in others as produced by processes of sedimentation, in others as produced by these in conjunction with underground waters, and in still others as produced mainly by underground waters.

Ore deposits which are precipitated almost solely by ascending waters will grade into those in which descending waters have produced an important effect, and thus there will be transition between classes (*a*) and (*c*). Similarly there will be every gradation between classes (*a*) and (*b*) and between classes (*b*) and (*c*). If this be so it will not infrequently happen that a single fissure may fall partly in one class and partly in another. Thus a single ore deposit may belong partly in class (*a*) and partly in class (*c*). However, in most cases the workable part of a deposit will largely belong to one of the three classes.

Not only are there gradations between different varieties of the ore deposits, but there are gradations between the ore deposits and the rocks; for the ore deposits in many cases are not sharply separated from the country rocks, but grade into them in various ways.

In answer to the above objection concerning gradations, it may be said that I know of no classification of ore deposits which has yet been proposed to which the same objection may not be urged with equal or greater force.

However this retort does not give any criterion by which the usefulness of the above classification may be tested. The test is, does this classification give a more satisfactory method of studying ore deposits than has heretofore been possible? Will an attempt to apply this classification assist mining engineers and geologists in accurately describing ore deposits? Will the classification to a greater extent than any previous one give engineers rules to guide them in their expenditure in exploration

and exploitation? By these criteria I am willing that the classification shall be tested.

As an illustration of the practical usefulness of the classification is the connection between genesis and depth. The character of a deposit in most cases will determine to which class it belongs. Where the ores are deposited by ascending waters alone it has been pointed out that this is favorable to their continuity to great depth. Therefore, where a given ore deposit has been shown to belong to this class, the expenditure of money for deep exploration may be warranted, although, as already pointed out, p. 757, such deposits may decrease in richness with depth. Where a deposit is produced by descending waters alone, the probable extent in depth is much more limited. In such cases, when the bottom of the rich product is reached, it would be the height of folly to expend money in deep exploration. Where the ore deposit belongs to the third class, that produced by ascending and descending waters combined, there will, again, be a richer upper belt composed of rich oxidized and sulphureted deposits which we cannot hope will be duplicated at depth. To illustrate: it would be very foolish, at Ducktown, Tenn., to sink a drill hole or shaft into the lean cupriferous pyrrhotite with the hope of finding rich sulphurets such as those which were mined near the level of groundwater. Those who have spent money in deep prospecting of the lean pyrrhotite in the Appalachian range will doubtless agree to this statement. Deposits produced by two concentrations may grade into the class produced by ascending water alone, and after the transition the deposit may be rich enough to warrant exploitation at depth; but if such work be undertaken it must be done with the understanding that the rich upper products will not be reduplicated at depth. It therefore appears to me that the determination to which of the classes of ore deposits produced by underground waters a given ore deposit belongs has a direct and very important practical bearing upon its exploration and exploitation.

C. R. VAN HISE.

REVIEWS

Secondary Enrichment of Ore Deposits. By S. F. EMMONS. Trans. American Inst. Min. Eng., Vol. XXX, 40 pp., 1900.

Enrichment of Gold and Silver Veins. By WALTER HARVEY WEED. Trans. Amer. Inst. Min. Eng., Vol. XXX, 25 pp., 1900.

In the exploitation of ore bodies it has been found that many deposits decrease in richness as depth increases. The explanations have been various. That the phenomenon is a far more general one than was once supposed, has only recently been recognized in its full significance. It may be expected to be very frequently met with, now that its real character has been found out, by all students of ore deposition.

It is now a well-known fact that as geological formations, ore-bodies as a rule are to be regarded as deposits originating very near the surface of the earth's crust; or, to be more precise, in the thin outer belt of the zone of fracture of the lithosphere. The unusual richness of many ore deposits at very shallow depths has come to be considered as due to local enrichment, often long after the first concentration has taken place.

From the viewpoint of origin, diminution of richness with depth is not, then, to be ascribed to actual depreciation in the original grade of the ore. The real status of the case is that the deposition of ore has, in the upper belt, undergone a greater or less augmentation in metallic content since the body was first formed.

Among those who have given the subject of ore genesis most attention, and especially among those who have approached the subject from the geological side, the rival theories of ascending solutions, descending solutions, and laterally moving solutions, no longer find countenance as distinct processes. Ore deposition may take place through all three means, which may have equal importance. After an ore deposit has once formed under special geological conditions, the secondary enrichment which it may undergo is believed to take place largely under the influence of the descending solutions.

In the exploitation of the ore-bodies, it all goes to show how vitally important is a full consideration of the geological structures presented at the time of the first concentration, and as subsequently assumed.

The keynote of Mr. Emmons' paper is given in one of the opening paragraphs, when he says that "admitting fully the general truth of the statement that the descending surface waters exert an oxidizing action, and hence that oxidation products within the reach of surface waters are the result of the alteration by the latter, I have been led to believe, by observations now extending over a considerable number of years, that under favorable conditions the oxidation products may be changed back again into sulphides and redeposited as such, thus producing what may be called a sulphide enrichment of the original deposits. . . . . Being rather a searcher after facts than a theorist, I am not deterred from accepting what may appear to me the correct reading of observed facts, because it seems to contradict generally accepted theories."

After briefly discussing the circulating waters of surface origin, the groundwater level, the deposition of oxides below water-level, and the deposition of sulphides, the author goes on to give an account of many cases of secondary enrichment which his wide experience has brought to notice. This account occupies the greater part of the paper. The three propositions following are believed to be substantiated by the geological evidence adduced:

1. That descending waters not only cause migrations, or transference and reconcentration, of the alteration products of the original vein-materials in oxidized form, producing in one place an enrichment, and in another possibly an impoverishment of the original deposit, but that in their further downward course the oxidized forms are frequently reduced and redeposited as sulphides, thereby producing a sulphide enrichment of the original vein-materials.

2. That this secondary enrichment of sulphides is not necessarily a reduction in the presence of organic matter, but is frequent where no organic matter can be supposed to be present. It occurs mainly in contact with the original sulphides of the deposits, and is, presumably, a result of chemical reaction between these sulphides and the materials brought down in solution by the descending waters.

3. That while this redisposition of sulphides in many cases appears to commence at or near the groundwater-level, it does not appear to

have a necessary connection with that level, and may under favorable conditions extend below that level for a distance as yet undetermined, the most important favoring conditions appearing to be recent or post-mineral fractures, which have admitted a relatively free and uninterrupted descent of these waters.

In conclusion, students are cautioned against making the inference too sweeping. "Until a much larger number of ore deposits have been studied with a definite purpose of determining how far they have been subjected to secondary enrichment, it does not seem safe to draw any far-reaching conclusions from the observations and suggestions noted above. It has long been recognized that the superficial alteration of ore deposits has often produced a very considerable modification of the original constitution of the deposit, and its alteration has so frequently been in the nature of an enrichment in the more valuable metals relatively to the original tenor of the ores, that it has given rise to the very hasty decision that all ore-deposits necessarily become poorer in depth, which is almost as unjustifiable as the old assumption by the miner, that the nearer he got to the source of his ore in the unknown deposits, the richer it would become.

"The fact that ores under some conditions may be removed and redeposited as sulphides, even below groundwater-level, opens a wide field of possibility in accounting for the unusually rich bodies of ore that are in some mines found in the middle levels, and have been fruitlessly sought for at greater depth. In many cases these have undoubtedly resulted from a concentration of material leached down from the upper portions of the deposit as they have been worn down and carried away by denudation. Especially in the case of large bodies of pyritous ore carrying small proportions of more valuable metals, is a concentration of those metals by downward percolating solution to be looked for. It is, however, not yet safe to say that all rich bonanzas in vein deposits have necessarily been formed in this way."

The paper by Mr. Weed gives a brief statement of the theory enunciated in a former contribution. The principles are applied more particularly to the deposits of the precious metals, with special emphasis laid upon the dependence of such enrichments upon the presence of iron sulphide in the primary ore, and upon the structural features which control the circulation of the enriching solutions below groundwater-level. The discussion is largely of Montana deposits, which the author has been engaged in studying for several years past. Regarding

the theoretical chemical changes, those taking place in each of the several zones are considered in detail.

Leaching out of the metals from the portion of the vein lying above groundwater-level is considered as the main source of the enriching materials. The alteration at the surface leaves the iron as a gossan, while the waters carrying the gold, silver, copper, and other metals in solution trickle downward through the partially altered ores into cracks and water-courses which penetrate the ore-body below the water-level. The first of the process is, therefore, the leaching of the lean ores which occurs in the superficial alteration of the vein. In weathering, the sulphides oxidize according to their relative affinity for oxygen and inversely as their affinity for sulphur. It is concluded from the evidence that ore-bodies lacking in iron pyrite will not show enrichment, thus explaining the absence of any such phenomena in the pure silver-lead bodies of the Coeur d'Alene district and elsewhere.

The observations of the author on the effects of physiographic and climatic changes, and on the changes of water-level, are of exceptional significance: "Active degradation favors the accumulation of enrichment, while prolonged degradation of a region, resulting from physiographic revolutions, may result in successive migrations of material and the accumulation in a relatively shallow zone of the metals derived from many hundreds, and possibly thousands, of feet of the vein worn away in the degradation of the land. Climatic conditions, rainfall or aridity, warmth and rapid alteration of vein fractures, are agents affecting surface weathering, and hence, also, enrichment.

"Active degradation of a region, that is, rapid weathering, favors enrichment by the quickness with which it removes the upper already leached part of the vein, so that a larger amount of the vein-matter is lixiviated in a given time than would result from the slower wasting of the land. Such enrichments are favored by high latitudes. Moreover, the mountainous regions are those in which secondary fractures are most apt to be found.

"Prolonged degradation is favorable for a similar reason, since time is a factor in enrichment and changes in elevation, etc., affect the rate and the progress of decay of the vein; while the crustal movements accompanying the physiographic changes favor fracturing of the earlier deposit, increasing facility of leaching and place for deposition. If a region passes through several cycles of erosion and elevation, it is evident that their result is likely to be a succession of enrichments in

which not only the original ore is leached, but the earlier enrichment deposits migrate downward. At Butte, Mont., the region has passed through several very pronounced changes in elevation since the formation of veins in Tertiary time. In early Tertiary time the present topography of the region was blocked out, and mountain ranges and deep valleys carved. This was succeeded by earth movements by which the streams became clogged or the valleys dammed, forming lakes; while volcanoes broke out at numerous places and showered ashes and scoria over the region. The valleys were silted up or in part filled with volcanic débris before crustal movements drained the valleys and altered the divides. More recent movement, possibly still continuing, is marked by faults and a reversing of the stream courses. The old valley at Butte is filled by hundreds of feet of débris, and a mountain wall 2500 feet high marks a north and south fault-line. These changes all caused a migration of water-level facilitating the processes of weathering and enrichment, and the great bodies of rich copper ores of the region are believed to be in part due to this cause."

CHARLES R. KEYES.

Enrichment of Mineral Veins by Later Metallic Sulphides. By WALTER HARVEY WEED. Bull. Geol. Soc. Am. Vol. XI, pp. 179–206, 1900.

The author calls attention to the occurrence of localized masses of exceptionally rich ore in mines of copper, silver and zinc, which he undertakes to explain as the result of enrichment by processes subsequent to the deposition of the lower grade ore. The paper attempts to show that these richer bodies of sulphide ore are formed by the redeposition of material leached from the vein, generally by superficial waters, and to show the chemical and mineralogical changes involved, as well as the physical conditions under which redeposition took place. The ores in question are chiefly the high grade sulphides.

He describes three zones; that of oxidation, that of sulphide enrichment, and that of primary sulphides, and refers to the writings of DeLaunay, Prosepny, Penrose, Emmons and Kemp in this connection. In discussing the chemical and mineralogical changes supposed to take place, he compares unaltered and altered ore and drainage waters observed by himself and cites freely from the literature of the subject, concluding that together they show that the original ore is

leached by surface waters, which take into solution various metals and passing downward meet with and are decomposed by the sulphides of iron present in the unaltered ore, resulting in the redeposition of new sulphides of the metals.

This is followed by a description of the mode of occurrence of secondary sulphide ores of copper, silver, and zinc, as studied by the author and others. The enrichment in many cases proceeds along barren fractures producing bonanzas. In others it forms films, pay-streaks, or ore shoots in the body of leaner original ore. In still other cases the alterations are produced by deep-seated uprising waters acting upon the vein. As a consequence of these processes veins do not increase in richness in depths below the zone of enrichment.

J. P. I.

Origin and Classification of Ore Deposits. By CHARLES R. KEYES. Trans. American Inst. Mining Eng., Vol. XXX; 34 pp., 1900.

The various attempts that have been made in the past to formulate a rational and at the same time a useful classification of ore deposits have met with only indifferent success. The fundamental factor in the proposed scheme by Dr. Keyes is geological in nature. It is based upon the principle that local deposition and specific form of the ore body is dependent upon geological structures, and these largely govern also the exploitation of the ores. This is believed to be as nearly as it is possible to approach a purely genetic arrangement. The great geological processes are made the governing principles.

Although the present memoir discusses only the classificatory aspects of the ore deposits, it is an application of the modern principles of petrology, and especially those dealing with the processes involved in general rock metamorphism, and it opens the field for fuller explanations and applications of these principles.

Three propositions are emphasized: First, ore bodies with few exceptions are regarded as essentially surface deposits—that is, they are considered as confined to a very thin zone near the earth's surface, or more precisely in the outer belt of the zone of fracture of the lithosphere; second, most of the worked deposits of the globe are thought to be of very late geological formation, probably few dating back before the Tertiary; third, ore bodies are believed to be concentrated chiefly

by circulating waters that have come up from below, down from above, or in from the sides, it being immaterial from which direction.

Of recent years there has been a growing tendency for the large mining companies to pay more attention to the geological features of their properties, and in many cases a regularly trained geologist has been employed. Dr. Keyes emphasizes this fact when he says that "When a specially trained geologist undertakes to make an investigation of a mining property, he first gets his bearings, as it were, with regard to the geological structure of the region and the distribution of the rock formations. At once he eliminates nine tenths of the chances of failure in arriving at the best plan for practical operation. Instead of a great game of chance, the development becomes a strictly business proposition."

After briefly discussing the nature of ore deposits, the general methods of ore formation, and the character of the literature, the criteria for ore classification are formulated. The following table sums up the proposed scheme:

CLASSIFICATION OF ORE DEPOSITS.

Groups.	Categories.	Miners' Forms.
I. HYPOTAXIC. Mainly surface deposits.	Aqueous transportation.	Placers.
	Residual cumulation.	Pockets (in part).
	Precipitative action.	Bog-bodies, some beds, layers.
II. EUTAXIC. Chiefly stratified formations.	Original sedimentation.	Beds, strata, layers.
	Selective dissemination.	Impregnations (in part).
	Emponded amassment.	Masses (in part), some segregations.
	Fold-filling.	Saddle-reefs.
	Crevice accretion.	Gash-veins, stock-works (in part).
	Concretionary accumulation.	Nodules.
	Metamorphic replacement.	Fahlbands (in part), beds.
III. ATAXIC. Predominantly unstratified and irregular bodies.	Magmatic secretion.	Masses (in part), some lenses.
	Metamorphic segregation.	Stocks, lenses.
	Fumerole impregnation.	Contact-veins, some impregnations.
	Preferential collection.	Chambers (in part), some pockets, linked-veins.
	Fissure occupation.	Attrition-veins (in part), some linked-veins, true veins.

The principal points which the memoir dwells upon are:

1. The main feature wherein the scheme of classification offered differs from others is in the prominence given to geological occurrence and the direct operation of the geological processes as essential factors in the genesis of ore bodies.

2. The nearest approach to a purely genetic classification of ore deposits is believed to be found in their geological relationships, as determined by the great groups of geological processes, and not in their direct chemical formation or physical shapes.

3. The chemical reactions so widely used as criteria of ore classification are to be regarded as general agencies, and therefore they are not available in the specific determinations of the various classes of ore bodies.

4. In the discovery and exploitation of ores, structure is of first importance, that is, the structure of the inclosing country rocks.

5. The primary groupings of ore bodies appear to be best indicated when based upon their geological occurrence, as governed by the nature of geological processes operating.

6. The secondary groupings appear to be best based upon the general form of the ore bodies as geological formations produced by the grander geological agencies.

7. The ternary groupings are best based upon the specific phases of the geological processes involved in the formation of ores as ore bodies.

8. The source of the ore materials is an unessential factor in their classification, the great practical question being, how are ores best exploited? In this connection it matters little what was the original condition of the ores. Nor have we to do very much with the detailed, complex, and usually fanciful chemical reactions that are supposed to take place before the final stage of the ore, as we find it, is reached.

9. Ore bodies of very similar appearance may be formed by very different methods—a fact which, while apparent in all classifications, does not necessarily vitiate any.

10. Finally, the proposed scheme is merely suggestive. It is the barest outline of what is believed to be capable of much farther expansion and development into a comprehensive, rational, and practical general plan.

C. F. M.

Éléments de Paléobotanique. By R. ZEILLER. 8vo, pp. 421, with 210 illustrations. Paris: Georges Carré et C. Naud, 1900.

The great needs of recent years in Paleobotany have been a summary of the scattered materials and the delimitation of well-founded data from data that are more or less uncertain. A great stride forward has been taken along these lines and as a result we are in a position to speak more categorically as to plant fossils. The first part of Professor Seward's work appeared sometime ago and has been reviewed in these pages[1]. Almost simultaneously three valuable works have recently appeared, one in English by Professor Scott, one in German by Potonié, and the one which is the subject of this review. The standpoint of the three works is somewhat different, Scott taking the standpoint more of the morphologist, Potonié of the stratigrapher, while Zeiller combines the botanical and geological standpoints, though giving more emphasis to the botanical side. More than any book that has yet appeared, this is a book to be used with impunity by general readers and elementary students. The first chapter treats of the various methods by which plant fossils have been preserved, then follows a chapter on classification and nomenclature. The body of the book, of course, is made up of descriptions of the various fossil forms treated in order. The cuts are simple but clear and good, and the descriptions are doubtless the shortest and clearest that are found anywhere.

The conservatism of the author is shown at many points, and the difference between established and hypothetical data is clearly brought out. As an illustration of this, Zeiller constantly distinguishes between forms based on leaves and forms based on reproductive organs, as in the ferns. There are interesting discussions of the Sphenophylleæ and the Cycadofilices, though the author does not go so far as some in putting these forms in great groups by themselves.

At the close of the book are two chapters of extreme interest. The chapter on the succession of floras and climates is wonderfully meaty, and it is doubtful if a better summary of the known facts was ever written, certainly not in a shorter compass. The author theorizes but little from the facts presented, and such deductions as he makes in regard to climate are extremely conservative. The last chapter must be somewhat startling to many readers, as Zeiller thinks there is very little evidence from fossil plants in favor of gradual evolution. He states that in almost every case, species, genera, families, and

[1] JOUR. GEOL.: Vol. VI, p. 436, 1898.

groups appear highly specialized and in their permanent form from the first. So-called intermediate forms like Cheirostrobus appear long after the forms they are supposed to connect. Genera and species that vary now have always varied and the limits of variation now and in the past have been the same and definitely prescribed. In short Zeillar believes that the evolution of all groups is a matter almost purely of speculation. Doubtless most scientists will fail to accept Zeiller's views as to evolution, and yet it may be well to put a brake now and then to unlimited speculation ; a perusal of Zeiller's final chapter certainly compels one to do that.—H. C. COWLES.

A Topographic Study of the Islands of Southern California. By W. S. TANGIER SMITH. Bulletin of the Department of Geology. University of California, Vol. II, pp. 179–230. 1900.

This bulletin involves an account of certain islands which have been studied in the field, and of others which have been studied from maps only. Following a description of the general topography of the islands, there is a somewhat full discussion of certain coastal features, especially of wave-cut terraces, and of wave and current-built features. This discussion is incisive, and will be of service to the student of coastal topography.

Following the descriptive matter there is a sketch of the history of the islands, from which the following extracts are made:

> It is generally assumed that the broad physical features of the Pacific Coast were largely developed during the prolonged period of erosion between the Miocene and Pliocene,[1] and that these forms have been modified more or less by subsequent movements, both general and local, as well as by subsequent erosion and deposition. During the Miocene the land was depressed, as indicated by the Miocene deposits, the nonconformity between these and the Pliocene deposits showing a period of subaerial erosion, during which the land was more elevated than at present. This period of elevation and erosion was followed by the Pliocene depression, during which deposits of great thickness were laid down in favorable localities, the larger Miocene valleys being filled to a greater or less extent with deposits which have since been re-excavated to a greater or less extent.

[1] By the long interval between the Miocene and Pliocene is doubtless meant the long interval between the deposition of the California coastal Miocene, and the Pliocene of the same region.

During the post-Miocene interval, it is probable that all the islands then differentiated were mountainous masses belonging to the mainland. Judging from their topography, and the apparent genetic relationships of those of the northern group, the forms then existing probably included all the present islands, except San Nicolas and San Clemente. The latter appears not to have been elevated till the close of the post-Miocene period, or early in the Pliocene depression, and it is probable that the elevation of San Nicolas occurred at about the same time. The disturbance at this time seems to have been general for this whole region, including both faulting and folding, and leading not only to the differentiation of these two islands, but also, probably, to a greater elevation of all the other islands. Although the forces operative in these movements are believed to have acted intermittently from that time to the present, it is thought that they were mainly effective then; and that any later movements have been of minor importance in relation to the general movements of the California coast, since the highest elevated terraces of San Clemente and the leveled summits of Santa Cataline and Santa Rosa still closely correspond in altitude with the highest terraces on the mainland, and, going farther north, with the upper limit of the Pliocene delta deposits along the Tres Pinos Creek.

The post-Miocene elevation of the coast was followed by the Pliocene depression, during which the sea stood for a long time some 1500 feet below [above ?] its present level as shown by the highest terraces, the planation of the island summits, and the delta deposits just referred to. Whether this was the full extent of this depression for the southern coast cannot be stated from the evidence at present available. During this depression, at first Santa Cataline, San Clemente, San Pedro Hill, Santa Cruz, and Santa Rosa, all probably existed as islands; or, in the case of Santa Cruz and Santa Cataline, as two or more small islands. At this level the ocean remained, cutting away the tops of these islands, till in the case of San Pedro Hill, and perhaps of Santa Rosa also, they were probably wholly truncated, leaving submarine banks like those of the region today. It is possible that San Nicolas was also above sea level at that time, and has since been planed off to its present lower level. Of San Clemente there remained a small nucleus, near the center of the northern half of the island. Santa Cataline was reduced to a small island lying to the north of the center of the present larger division of the island, with probably one or more distant rocks, or smaller islands, toward the present extremities of the island. Santa Cruz, at that time probably existed as a single narrow island, or a line of islands, with a length of at least seven miles, and formed from the northern ridge of the western or main division of the present island. Then, as now, Santa Cruz was probably the highest, if not the largest, of the existing islands.

This depression was followed by a post-Pliocene elevation, as shown both by the present elevation of the Pliocene deposits, and by the elevated coastal

terraces. . . . . The writer is inclined, from present information, to the view of one general elevation of the California coast in post-Pliocene times, accompanied by minor oscillations, and by local differential movements, such as that called for, for example, in the formation of San Francisco Bay. . . . .

It is probable that while the oscillations of post-Pliocene times have been sufficient to connect the northern islands with the mainland, none of the southern islands have had such connection since the post-Miocene period of erosion.

The most recent movement of the coast, as indicated by drowned valleys and submarine features, is a comparatively slight depression, the evidence for which, on the southern California coast, has already been given in detail. The later history of the coast seems, therefore, to be most satisfactorily summed up in a single post-Pliocene elevation, interrupted by minor reverse movements, of which this most recent depression is probably one.

Whether or not future investigation shall lead to modification of the details of the coastal movements as here outlined, is immaterial to the main conclusions of the present paper ; the principal point which it aims to establish being the fact that the latest general movements of the islands and coastline of southern California have been the same. R. D. S.

CORRECTION.

In Professor Spurr's article on "Succession and Relation of Lavas in the Great Basin Region," in the last number of the JOURNAL, the caption of the table opposite page 642 should read : "Provisional Correlation of Tertiary Lavas in the Great Basin," not "Great Britain."

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